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"PROGNOZ" AUTOMATIC STATIONS

V. A. Arkhipov et al

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LIST OF ACRONYMS

Acronym	Expansion
ANCh	Expansion not known
AR	Automatic measurement range expander
AS	Anticoincidence circuit
BP	Memory unit
D	Discriminator
$DD(E_i)$	Differential amplitude discriminator
DSG	Expansion not known
DT	Direct transmission of information
EP	Emitter repeater
ESG	Electrostatic generator
FEU	Amplifier for photo-electric cell
FS	Photoresistor
GI	Pulse generator
I	Intensimeter
IK	Integrating circuit
KYa	Expansion not known
LP	Linear transmitter
MD	Memory device
MF	Magnetic filter, Microphotometer
MM	Memory mode
OD	Expansion not known
ODI	" " "
ODS	" " "
ODT	" " "
OF	Selection device at front
OKM	Interrogating switch
OR	Expansion not known
PL	" " "
Pr	" " "
PS	Threshold circuit
PU	Switching device
RID	Radioisotope engine

RPZ	Expansion not known
RS	Reversive counter
S	Adder
S	Expansion not known
SBT	" " "
SD	Solar engine
SDA	Photodiode
SEZ	Expansion not known
SG	Signal generator
SGL	Expansion not known
SNEG	" " "
STS	Solar heat power plant
TM	Telemechanic
TS	Expansion not known
U	Amplifier
U_{sum}	Summing amplifier
UK	Amplifier switch
UPT	Direct current amplifier
VEU	Secondary electron multiplier
VLFO	Very low frequency oscillations

INTRODUCTION

The performance of scientific experiments to study space /2
using automatic stations, building such stations, equipping them with power systems, automatic control systems, radio-telemetry and a number of diverse scientific instruments requires the efforts of a number of collectives. Therefore, the construction of the "Prognoz" complex involved the participation of a collective composed of a number of institutes and planning organization of the Academy of Sciences of the USSR and the Ministry of Higher and Middle Special Education, including the following:

V. A. Arkhipov, G. N. Babakin,[1] V. V. Bezrukikh, A. P. Belyashin, Kh. S. Bleykh, A. V. Bogdanov, N. F. Borodin, O. L. Vaysberg, N. G. Valichnin, N. N. Volodichev, A. I. Vorob'yev, G. I. Volkov, N. L. Grigorov, K. I. Gringauz, V. P. Grigor'yeva, A. S. Grechkin, V. I. Gurenko, V. A. Gurnov, M. M. Demidova, N. V. Derevyanskiy, Sh. Sh. Dolginov, Ye. G. Yeroshenko, L.N. Zhuzgov, G. N. Zastenker, A. M. Zertsalov, V. Ye. Ishevskiy, V. N. Karechevskiy, S. I. Karkanov, G. Ya. Kolesov, V. F. Kopylov, P. G. Kotikov, M. I. Kudryavtsev, S. D. Kulikov, A. I. Kukushkin, R. S. Kremnev, V. T. Lasskiy, O. B. Likin, Ya. M. Likhter, V. N. Lutsenko, Yu. I. Logachev, S. M. Matveyev, A. S. Melioranskiy, Ye. I. Morozova, L. S. Musatov, N. F. Myasnikov, N. M. Nazarov, N. I. Nazarova, V. P. Nikiforov, V. A. Netkin, F. M. Ovozhenko, V. M. Pankov, V. P. Panteleyev, V. A. Paramonov, A. A. Petrov, Z. F. Petrova, N. F. Pisarenko, B. V. Polonev, N. G. Putin, D. N. Pyak, V. V. Ratnikov, M. A. Rozenberg, S. P. Ryumin, I. A. Savenko, S. S. Sergeyev, I. N. Selivokhin, V. A. Serebrennikov,

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[1]Deceased

*Numbers in the right-hand margin indicate pagination in the foreign text.

G. A. Skuridin, A. I. Sladkova, V. I. Slyn, V. D. Sokolov, A. A. Suslov, Ye. M. Skhodnev, G. M. Teterevov, Yu. V. Trigubov, V. N. Ustinovshchikov, V. I. Fuks, N. A. Frolova, M. Z. Khokhlov, M. I. Chinenkov, G. I. Chukhray, K. N. Sharvina, V. M. Shamolin, I. P. Shestopalov, V. F. Shesterikov, I. V. Estulin, B. N. Yashin.

In accordance with the program for the study of outer space, the "Prognoz" automatic stations were launched in the Soviet Union on the 14th of April 1972 and the 29th of June 1972 [1]. These stations were intended for a study of solar activity and its influence on the interplanetary medium and the Earth's magnetosphere. These studies constitute a complex investigation of various physical parameters of the interplanetary medium and near (circumterrestrial) space. Such parameters as the plasma fluxes ("solar wind"), magnetic field, particles of solar cosmic rays and electromagnetic radiation are interrelated in certain ways (just how is the object of our study), influencing each other. The variations in these parameters with time are influenced by processes on the Sun. /3

The flights of spacecraft have shown that nearly every solar flare is accompanied by the expulsion of an enormous quantity of charged particles with various energies into the surrounding space. Sometimes their energy is so great that they pass readily through the hull of a spacecraft, influencing the working capacity of the instruments, and may constitute a definite hazard to cosmonauts.

Observations carried out aboard the "Prognoz" stations, outside the magnetosphere on the Earth, in combination with data from ground observatories, carrying out a continous monitoring not only of the condition of the Sun but of the magnetic field of the Earth, cosmic rays, and so forth are used to study the mechanism of solar activity and relationships between the Sun and Earth.

In addition, such research is required for a scientific forecasting of the radiation situation in space.

1. "Prognoz" Space Station. /4

The station was injected into the calculated orbit in two stages (Figure 1). Initially the station was placed in a

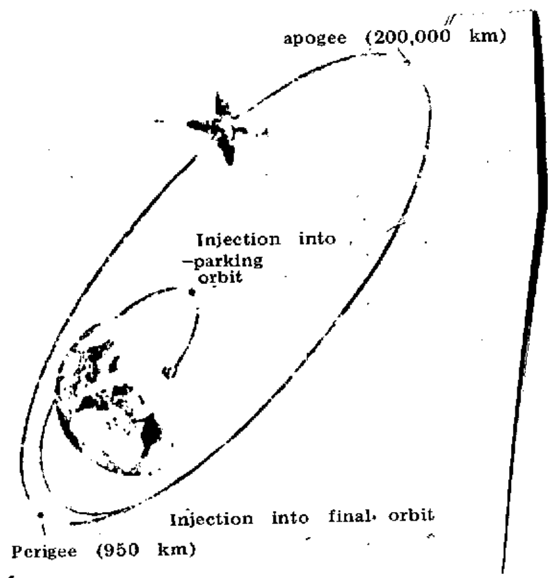

Figure 1. Diagram of the flight of "Prognoz Station".

parking orbit together with the final stage of the launching rocket, with the following parameters: maximum altitude above the surface of the Earth--505 km; minimum altitude above the surface of the Earth--238 km; inclination to the plane of the Earth's equator--65°. At the 68th minute of the flight, on command from the programmed timer, the engine of the launch rocket was ignited and gave the station additional velocity required to inject it into the calculated orbit. The initial parameters of this orbit were: minimum altitude--956 km, maximum altitude--200,000 km, inclination to the plane of the equator--65°; the period of rotation around the Earth was about 97 hours.

It should be pointed out that the injection of an artificial earth satellite into such a highly elliptical orbit was first accomplished in the Soviet Union.

This orbit was distinguished by a significant change in parameters and particularly the minimum altitude above the surface of the Earth, under the influence of the fields of attraction of the Sun and Moon. This change in altitude could reach 400 or more kilometers per pass, amounting to either an increase or a decrease. Hence, the injection of a satellite into such an orbit, to ensure that it would remain there for a sufficiently long period of time, constitutes a difficult ballistic problem. One of the important factors in its solution is the selection of the most favorable date for launching from Earth. A launch at this time must guarantee the minimum altitude of the orbit at perigee at which the prolonged ballistic existence of the station would be ensured. The calculated highly elliptical orbit of the "Prognoz" station is very /5
sensitive to the magnitude and direction of the velocity vector when the station separates from the launch rocket. Thus, a deviation in velocity of 1 m/sec from the calculated value could lead to a change in the maximum altitude of the orbit above the surface of the Earth of up to 1200 km. Therefore, the injection

of the "Prognoz" station into the calculated orbit required a high level of accuracy from the functioning of the control and executing elements of the station.

The measurement of the trajectory which were carried out showed that the orbital parameters of the station were close to the calculated values.

The "Prognoz" artificial earth satellite was built in the shape of a hermetically sealed cylindrical pack, 1500 mm in diameter and 1200 mm long, sealed at both ends with spherical caps. At a distance of 200 mm from the upper cap, the pack has a flanged separation along the perimeter, by means of which the lower part of the pack (base) is connected to the upper part--the lid.

On the upper cap of the pack is a frame to which the sensors of the scientific instruments are attached; it carries the sensors of the solar orientation system, the radio equipment antennas and the electronic elements of scientific instrumentation. The cylindrical part of the container is fitted with four panels of solar batteries, some of the sensors and blocks of scientific apparatus, operating elements of the solar orientation system and tanks of nitrogen, as well as a thermal damper. At the ends of two of the solar battery panels there are frame antennas of the "Cassiopeia" instrument and the magnetometer rod. On the lower cap of the container are the sensors of scientific instruments, sensors of the solar orientation system, and a radio antenna. A general view of the station is shown in Figure 2.

In the launch position, the solar battery panels, the magnetometer rod and the "Cassiopeia" antenna are in a folded position. They are deployed after the satellite separates from the launch rocket. /6

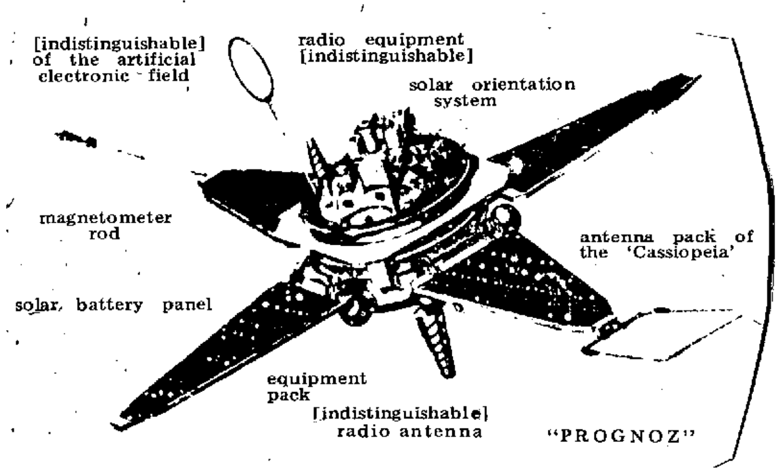

Fig. 2. General view of "Prognoz" station.

Within the pack there are frames for holding instruments --upper and lower. The upper one is attached to the lid, and the lower one is attached to the base. The frames carry scientific instruments, apparatus in the radio-telemetry complex, equipment in the solar orientation system, elements of the heat regulating system and the power supply system. On the upper cap and along the lateral surface of the container there are hermetically sealed joints for the antenna-feeder devices, scientific instruments and electrical power supply system.

The entire surface of the pack, with the instruments mounted on it, is covered with shielding-vacuum thermal insulation. The sensitive elements of the sensors and the lateral surface of the container remain exposed, serving as a radiator for the heat regulating system.

The satellite is fastened to the launch rocket by means of an adapter shaped in the form of a truncated cone. The upper part of the adapter contains a system for separation of the satellite. Separation of the satellite from the adapter is accomplished by means of four explosive bolts.

The weight of the "Prognoz" satellite following its separation from the launch rocket is 845 kg.

In order to solve the tasks assigned to it, the satellite is equipped with a number of scientific instruments, an onboard radio-telemetric system, a solar orientation system, a heat regulating system, and an electrical supply system.

The onboard radio-telemetric system, together with the equipment on the ground command-measuring complex, allows the onboard system to be controlled on command from Earth, permitting measurement of the motion parameters and collection of scientific and telemetric data aboard the satellite.

The radio telemetric equipment includes transmitters, /7
receivers, decoders, telemetric switches, encoding devices, highly directional antennas and other electronic equipment. Communications with the satellite is on the decimeter wavelength.

All during the flight, all of the scientific information is recorded on a special memory device (MD) which is part of the radio telemetric complex. The memory device records the information resulting from the operation of various onboard systems of the satellite. Transmission of the recorded information to Earth takes place during communication sessions. The system has provision for direct transmission of information (DT).

A TM* system with time division of channels, and with cyclic interrogation of the output parameters of the scientific instruments once every 41 seconds in the memory mode (MM) and once every 0.08 seconds in the direction transmission (DT) mode is used. The measured voltage can vary from 0 to 6.3 volts. The TM system forms a pulse, which is synchronous with the interrogation cycle, to control the internal switching devices of the scientific instruments. The telemetry system contains a switch with an interrogation capacity of once every 27 minutes for the recording of slowly changing parameters. When switching the operating mode of the TM system from MM to DT and vice-versa, the corresponding control signals are transmitted to the scientific instruments. The radio telemetry system includes special programmed timers which formulate commands in a certain sequence, controlling the operating modes of the instruments. It is also possible to change the operating modes of the instruments on command from Earth.

The solar orientation system makes it possible to place the lengthwise axis of the satellite (X-axis) in any position with respect to the Sun. By causing it to turn, the satellite is given gyroscopic stabilization in space, necessary for normal function of the scientific instruments and solar batteries. The rotation of an artificial Earth satellite around its axis of orientation is used to study the angular characteristics of the fluxes under study. For this purpose, some of the sensors are mounted at angles of 45°, 90° and 135° to the axis of orientation. /8

The solar orientation system contains solar sensors, angular velocity sensors, a logical unit, executive elements and

* Telemechanic

auxiliary electronic blocks. The solar sensor is intended for "finding" the Sun and forming signals of the value of the deviation of the lengthwise axis of the satellite from the direction of the Sun. The sensors of angular velocity are intended to transmit signals to rotate the satellite and measure the angular velocities of its rotation.

The logical unit develops commands to control the auxiliary elements in accordance with the signals from the sensitive elements and the established logic of operation.

The system for controlling the temperature situation is intended for keeping the temperature of the gas in the instrument container and the individual elements of the satellite within set limits. The required temperature conditions are ensured by passive and active means of temperature regulation. In order to maintain the desired temperature conditions for the apparatus located in the hermetically sealed container, in addition to "passive" temperature regulating devices "an active" system of temperature regulation is employed which operates by means of special automatic devices to change the thermal exchange condition as a function of the temperature in the container. An inert gas with which the container is filled is used as the heat conductor.

The temperature conditions of the equipment located inside the container are maintained by thermal contact with the hull of the container and its outer surfaces are shielded by plates /9
made of a screen-vacuum thermal insulation and by using the radiant solar flux. The thermal conditions of the solar batteries is ensured by applying special optical codings to the surface of the panels.

The electrical power supply system provides electrical energy for all of the onboard systems of the satellite. It was built according to the "generator-buffer battery" system. A solar battery is used as the electrical energy generator, and the buffer battery is a chemical power source.

2. Composition of the Scientific Instrumentation.

In order to carry out the program of research into the fluxes of charged particles of different types, characteristics of plasma and solar wind, electromagnetic radiation, and radiation of the magnetic field, various methods of measurement are employed. The entire program consists of 15 instruments which are described briefly below.

The majority of the recorded output parameters consist of the counting rate of pulses from certain sensors. A natural time unit for this purpose is the interrogation period of the TM system parameters. The difficulty in recording the information obtained consists first of all in the wide range of variations and counting speed, and, secondly, in the limited transmitting capacity of the TM system. It is also necessary to record rather rapid changes in fluxes and also to ensure that the number of pulses transmitted have the required statistical accuracy. These facts have led to the use of essentially two systems for recording impulses. In those cases when the requirements for measurement accuracy as to the counting rate are not great but do require a considerable dynamic range to be covered, logarithmic /10
intensimeters are used, with a dynamic range of counting rate up to three orders of magnitude. In other instances, trigger counting registers of a different type are employed. The state of three or more successive triggers is encoded by means of adding devices, in the form of a stepped DC voltage from the TM system being recorded. In a number of instruments, linear or logarithmic amplifiers are employed whose output voltage is proportional to the value of the recorded current or voltage.

The SEZ*-3 instrument is intended for measuring protons, alpha particles, and groups of nucleii in several energy ranges. In order to measure the proton fluxes in the energy range from 1 to 4.7 MeV in the following direction: from the Sun, toward the Sun, and at an angle of 90° to the angle of rotation of the satellite, individual silicon detectors are used with a sensitive layer thickness of 50 microns. In the 90° direction, alpha particles with energies of 4-19 MeV and protons from 14 to 35 MeV are also measured (silicon detector 1.8 mm thick). Each individual detector is mounted in a closed brass collimator; the inlet window of the detector is covered by aluminum foil 7 microns thick. The signals from the detector, following amplification, are sent to the integral discriminators, which have a threshold ($U_{threshold}$) based on the corresponding output of energy in a crystal ΔE.

Measurement of the protons, alpha particles and nuclear groups in other energy intervals takes place by using a spectrometer from 5 "through" silicon detectors (D-1-D-5) with a sensitive layer thickness of 200 microns. A diagram of the spectrometer is shown in Figure 3. Sorting of the particles by charges is accomplished by means of a simultaneous measurement of the path intervals (ΔR) and the energy developed in one of the detectors (ΔE). Detectors D1 and D2 form a telescope for determining the solid angle for collecting radiation of 30°C. In order to reduce the background of particles coming from outside the aperture angle, the telescope is covered with a brass shield /11
5.33 g/cm^2 thick. The D2-D5 detectors, separated by aluminum and tungsten filters, are detectors of particle parts. Two paths have been selected: E_1 and E_2; the method of selection of pulse coincidence from D_1 and D_2 and anticoincidences from D3, E_1, or coincidences from D1, D2, D3, and D4 and anticoincidences from D5. In the first case, particles with a path interval from 0.1 to 0.3 g/cm^2 are measured;

* [Translator's note: Expansion not known.]

in the second, in the path interval from 0.7 to 2.1 g/cm^2. An amplitude analysis of the impulses in the detectors D1 or D3 is carried out by means of two differential amplitude analyzers with five windows each.

The instruments also include four gas-discharge counters (type STS*-5); surrounded by aluminum or brass shielding, with the thickness selected so that protons with threshold energies shown in Table 1 can be recorded. The geometric factor of the counters for isotropic flux of penetrating particles is 4.3 cm^2. The counters make it possible to record the integral fluxes of charged particles.

The ŠEZ-2 instrument serves for measurement of the charge composition of cosmic rays with energies E $\geqslant$ 500 MeV/nucleus. It consists of a Cherenkov counter [2] located between two scintillation detectors which form a telescope with an aperture angle of 41°. The amount of matter which is located ahead of and between the scintillation counters makes it possible to use them to record protons with energies equal to or greater than 100 MeV. Figure 4 shows a schematic diagram of the instrument. The signals from the scintillation counters enter the double coincidence circuit. The impulses from the Cherenkov counter are fed to the circuits for integral and differential analysis, which are controlled by the double coincidence circuit. The intensity of the flashes of the Cherenkov detector is proportional to the square of the nucleus charge, which makes it possible /12
to determine the charge of the particles passing through the instrument through amplitude selection of pulses. Integral analysis revealed six groups of amplitudes: within the limits from 15 x 10^{-3} to 115 V. The differential analysis system consists of two 64-channel recorders [3]. Differential analysis makes it possible to have a detailed recording of the amplitudes of the Cherenkov flashes.

* Solar heat power plant

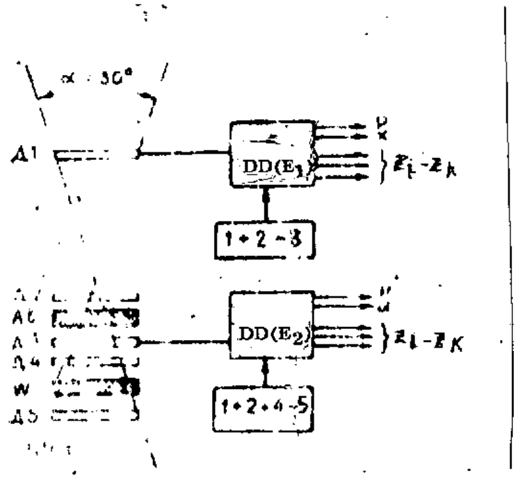

Fig. 3. Diagram of silicon telescope of the SEZ-3 instrument. (DD(E_i))--differential amplitude discriminators.

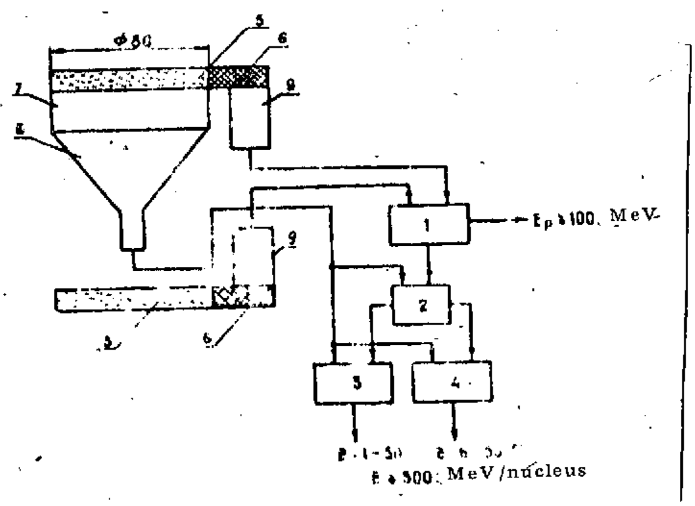

Fig. 4. Diagram of Cherenkov spectrometer in the SEZ-2 instrument. 1,2--dual coincidence circuit; 3--integral analysis circuits; 4--differential analyzers; 5--plastic scintillators; 6--light pipe; 7--Cherenkov radiator; 8--photomultiplier (FEU*-56); 9--photomultiplier (FEU-16).

* Amplifier for photo-electric cell

The SA*-2 instrument measures low-energy protons and electrons. In this instrument, an open CsI (Tl) crystal is used for measuring the proton fluxes in the energy range from 30 to 210 keV, in a direction perpendicular to the axis of rotation of the satellite; the crystal is 100 microns thick and is mounted directly on the photocathode of the FEU-85 with small corresponding noises. To deflect the electrons with energies less than 2 MeV in front of the detector there is a collimator with a permanent magnet deflector. Impulses from the anode of the FEU strike differential discriminators which divide the three energy intervals with self-consistent output into the recording system.

For measurements of low electron fluxes with E $\gg$ 30 keV, the SA-2 instrument is equipped with two identical systems. Each of them is composed of an end window counter (SBT-9) surrounded by a protective cap made of a plastic scintillator of the FEU in question and a deflecting magnet system (MF†) The thickness of the entrance window in both end window counters is selected to be the same. Only those charged particles are recorded which strike the end counters through the entrance window. Energetic particles which pass through the lateral surface of the counter are eliminated by the anticoincidence system. In one of these counters, the magnetic system is demagnetized and consequently the counter records protons and electrons. The second counter in the magnetic field records only the protons. The readings from the two sensors are fed to the recording system. The difference between these readings gives the integral flux of electrons with energies above 30 keZ. /13

The RPZ* instrument is used for measuring fluxes, spectra and angular distribution of electrons with E = 3, 30-140 keV. The instrument includes 8 miniature sector magnetic spectrometers with dual focusing and a deflection of 180° (Figure 5), set to fixed

* [Translator's note: Expansion not known.]
† Microphotometer

energy levels. As electron detectors they employ small-scale end window counters of the SBT-18 type [4]. The impulses from the outputs of the counters enter the counting devices.

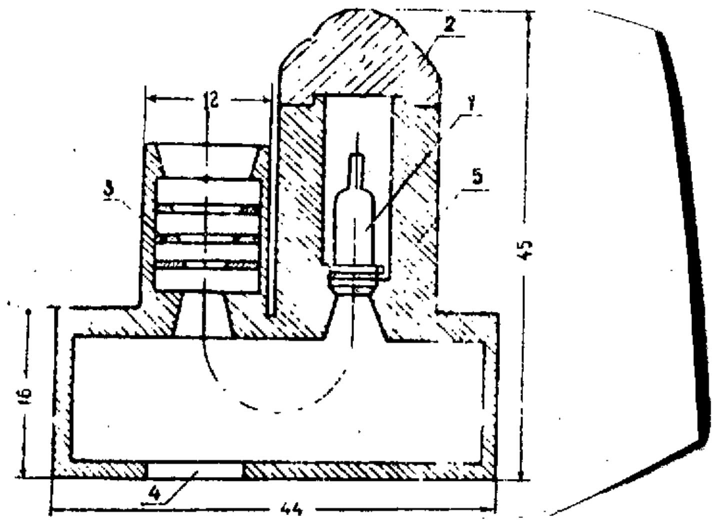

Fig. 5. Magnetic spectrometer of electrons of instrument RPZ. 1--gas discharge counter (SBT-18); 2--lead covering; 3--entrance colimator; 4--outlet window; 5--spectrometer housing.

To detect electrons with E = 3.8 keV, a CdS crystal is used whose current is proportional to the electron flux. The measured numbers of impulses in gas-discharge counters are connected both with the recording of electrons, for which the spectrometers are set, and with the readings given by the penetrating radiation. The instrument has a spectrometer with a demagnetized magnet (background sensor) for measuring the contribution of penetrating radiation. The readings from this sensor are calculated from the readings of the spectrometers. The magnetic spectrometers, which measure electrons with energies of 3, 40, 70, and 140 keV are aimed at an angle of 90° to the axis of rotation of the satellite. Two spectrometers (E_{e}^{-} = 70 keV) are aimed at an angle of 45° and 135° to the axis of rotation of the satellite. Miniature magnetic spectrometers have a comparatively low intensity and are therefore intended for measuring the spectrum of electrons during solar flares.

To measure the integral flux with E > 30 keV, the RPZ instrument (besides spectrometers) is equipped with two systems having magnetic filters similar to those used in the SA-2 instrument. They use end window counters of the SBT-18 type without protective caps against anticoincidence. The level of the electron flux, as in the previous case, is obtained from the difference in the readings of two end window counters [5].

The RS*-1 instrument is a spectrometer which serves to measure the fluxes of soft X-radiation from the Sun in the 2-30 keV energy range. The spectrometer consists of a proportional counter and an amplitude analyzer with four differential /14
channels (Figure 6). In order to cut down the readings caused

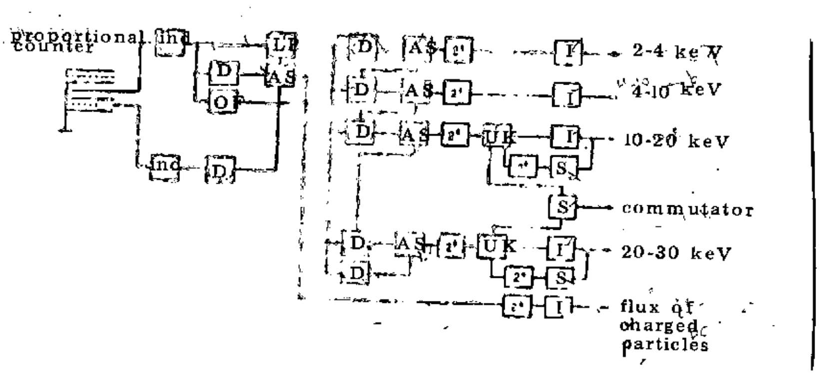

Fig. 6. Functional diagram of R.S-1 instrument: OF--selection device operating at the front; AS-- anticoincidence circuit; UK--amplifier-switch; S--adder; I--intensimeter; LP-- linear transmitter; D--discriminator; ind--indistinguishable.

* reversive counter

by charged particles in a proportional counter, a system of electrodes is used for producing anticoincidence impulses and a system for selecting electrical impulses on the basis of the rise time of the front. The time for collection of charges formed by an X-ray quantum and charged particles differ considerably and this makes it possible to carry out a separation of charged particles. The proportional counter, with a volume of about 400 cc's, is filled with a gas mixture of Xenon (90%) and methane (10%) at a pressure of 0.8 atm, and the entrance window of the counter has an area of 1 cm^2, covered with beryllium foil about 60 microns thick.

The SGL*-1 instrument is a scintillation spectrometer for soft gamma-radiation with E = 30-350 keV. The instrument uses a detector which is composed of a crystal of CsI (Tl) seven millimeters thick and enclosed in a plastic scintillator. The light flashes are recorded by an FEU-53 photomultiplier. The spectrometer measures the gamma radiation in the presence of large fluxes of charged particles. In order to exclude the impulses caused by charged particles, the instrument uses the method for separating the impulses from the scintillators of different types on the basis of their de-excitation time (the "Fosfich" method). The instrument has four differential channels, counting events in each channel separately. As we can see from Figure 7, the photomultiplier and scintillators are mounted in a lead cup which protects the detector against the soft component of charged particles.

The IK†-2P instrument serves for measuring the dose of cosmic radiation. The instrument is mounted inside the pressurized container of the satellite and measures the total dose from penetrating radiation and secondary ionized radiation originating in the material of the satellite. The instrument is composed of two ionization chambers and a STS-5 counter for counting the number of charged particles inside the satellite. The chambers

* [Translator's note: Expansion not known.]

† integrating circuit

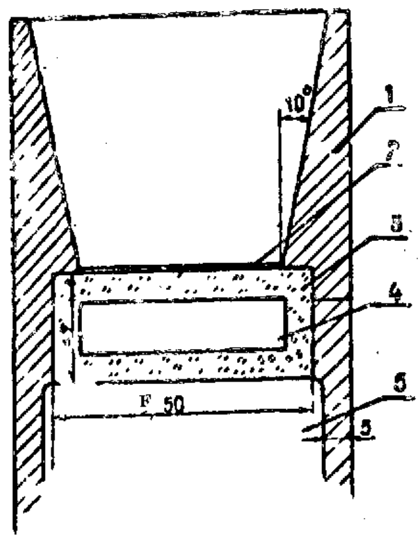

Fig. 7. Detector of SGL-1 gamma-spectrometer. 1--lead colimator; 2--aluminum foil, 100 microns; 3--plastic scintillator; 4--CSI (Tl crystal); 5--FEU-53 photomultiplier.

are filled with argon. The ionization current of the chambers is measured by the method of charge leakage by means of a special electrostatic relay mounted on the collecting electrode of the chamber [6]. The number of operations of the electrostatic relay is measured by a counting circuit. The chambers differ in their volume of gas cavity V and argon pressure P and therefore have different degrees of sensitivity to the dose of radiation. /15

The characteristics of the instruments intended for recording the solar cosmic rays, which were discussed above, are shown in the accompanying Table 1.

The D-140 instrument is intended for studying the characteristics of plasma in space near the Earth and in interplanetary space. The instrument measures the energy spectrum of the ion component in the energy range of 0 to 4 keV, the integral fluxes of ions and electrons, and is intended for measurement in interplanetary space, the transitional region, and the plasmosphere of the Earth.

The instrument contains four sensors--charged particle traps mounted on the external surface of the satellite.

Each trap consists of a system of several electrodes, a collector, and a number of grids, mounted in a metallic housing. The flux of charged particles striking the open mouth of the trap, is measured in terms of the current value at the target of the collecting electrode collector.

A modulation trap (PL-18) (Figure 8) measures the energy distribution of the ions using the method of flux modulation by means of the braking potential. The voltage as applied to the modulation grids of the trap consist of a sum of two voltages: DC and AC square waves with a frequency of about 1500 Hd. In order to obtain the energy spectrum a series of eight successive increasing values of modulating voltage is employed in the range from 0 to 4 kV with [illeg.] of each energy interval $E/E_{av} \simeq 0.45$. /20
As a collector in the trap, there is a resonance amplifier set to the frequency of the modulation.

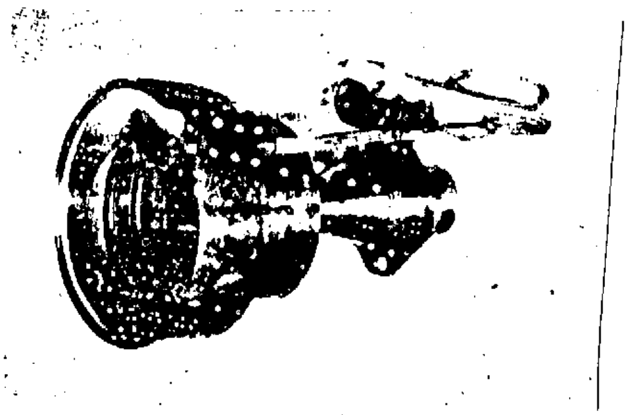

Fig. 8. Modulation trap PL-18.

No.	Instrument	Radiation	Method	No. of Detectors	Direction Relative to the Satellite-Sun Axis	Energy Drain V	Weight kg
1	2	3	4	5	6	7	8
1	SEZ-3 (Measurement of protons and average energy nucleus fluxes)	protons 1±4.7 MeV	silicic detector, 50 microns	3	0°,90°,180°	13	18.5
		α-particles 4÷18 MeV	"	1	90°		
		protons 14-35 MeV	silicic detector, 1.8 mm	1	90°		
		protons, α-particles 7.5÷14; 22.5-43 MeV/Nucleus	telescope of 5 silicic detectors	1	0		
		nucleus 3<Z<20 (3 ranges) with energies 8.5÷150 MeV/Nucleus	"				
		charged particles Ep>15.30.60 and 100 MeV	gas discharge counter from the STS-5 data unit with filters	4	—		
2	SEZ-2 (Measurement of the charge composition of higher energy nuclei	protons $E_p > 100$ MeV Nuclei Z = 2÷50 with $E_Z > 500$ MeV/Nucleus	Cherenkov counters regulated by scintillator telescopes	1	0°	5	8.5
3	CA-2 (Measurement of protons and low energy electrons)	protons 30÷210 keV	scintillator CsI(TP)	1	90°	6	11
		electrons $E_e \geq 30$ keV	100 micron SBT-9 end window counter with a magnetic filter and an anti-coincidence scintillator	2	90°		
4	RPZ (Measurement of fluxes and electron spectra)	electrons $E_e^- \geq 30$ keV	SBT-18 end window counter with a magnetic filter	2	90°	6	11.8
		electrons $E_e^- = 120$ keV	magnetic spectrometers constructed for energy of 3, 40, 80, 120 keV	6	90° (4X); 45° (1X); 135° (1X)		
		protons $E^+ = 60$ keV	magnetic spectrometer	1	90°		
		background of penetrating radiation	demagnetized spectrometer	1	—		
5	SGL-1 (Gamma radiation spectrometer)	Electromagnetic radiation 33-50 keV (4 ranges)	"Fosfich" - plastic with CsI(T1)	1	0°	2.5	5.6
6	RS-1	Electromagnetic radiation, 2.0-30 keV (4 ranges)	Proportional counter	1	0°	2.7	3.9
7	IK-2P (Measurement of radiation dose)	Ionizing radiation	ionized chambers with an electrostatic relay	2	4	1.6	3.5
		ionizing radiation	STS-5 gas discharge counter	1			

TABLE 1. Characteristics of Devices Intended For Recording Ionizing Components of Solar Cosmic Radiation.

TABLE 2.

Values Measured by the D-140 Instrument

No.	Sensor	Recorded particle	Measured values and measurement ranges	Accuracy, resolution	Scan Sector	Total measurement time
1	Modulation trap PL-18	P, He^{++} (φ_{sp} < g < 4keV)	1. $N = 10^6 + 10^9 cm^{-2} sec^{-1}$ 2. n_p(for E ≅ I eV) = $10 + 10^4 cm^{-3}$ 3. Spectrum E_p = 30eV + 4keV	±10 + 40% $\frac{\Delta E}{E_{av}} \cong$ 40-50%	Cone $\varphi = 0 + 360°$ $\theta = 0 + 50°$	One spectrum = 8 turns of the commutator, i.e., 5.5 min.
2	PL-40 Integral trap	p(E > 40 eV) ē(E > 70 eV)	$N_p = 5 \cdot 10^7 + 5 \cdot 10^9 cm^{-2} sec^{-1}$ $N_{\bar{e}} = 5 \cdot 10^7 + 5 \cdot 10^8 cm^{-2} sec^{-1}$		Cone $\varphi = 0 + 360°$ $\theta = 0 + 75°$	One count (once in 41 sec)
3	PL-46 Integral trap	p(E > φ'_{sp}) ē(E > 70 eV)	1. $N_p = 5 \cdot 10^7 + 5 \cdot 10^9 cm^{-2} sec^{-1}$ $N_{\bar{e}} = 5 \cdot 10^7 + 5 \cdot 10^8 cm^{-2} sec^{-1}$ 2. n_p(for E≅IeV) = 5 to $50 \cdot 10^3 cm^{-3}$		Cone $\varphi = 0 + 360°$ $\theta = 0 + 80°$ (for E≅IeV)= 0+180°	One count (once in 41 sec)
4	Total weight of apparatus – 10.0 kg, energy consumption, 8.5 W.					

Integral trap PL-40 (Figure 9) is intended for determining the total ion flux from the solar wind (when an energy $E_r > 40$ ev) as well as electrons with energy $E_{\bar{e}} \gtrsim 70$ eV. Two integral traps of the PL-46 type (Figure 10) are used for measuring the ion fluxes with energies $E_r > \varphi_{sp}$ (φ_{sp} is the potential of the satellite) and electrons with $E_{\bar{e}} \gtrsim 70$ eV. These traps have a hemispherical external grid which increases the scan sector of the trap for thermal ions (with $E_r \sim 1$ eV). Several characteristics of the integral traps employed are described in [7, 8]. /20

Table 2 summarizes the basic data on the measurements performed with the D-140 instrument.

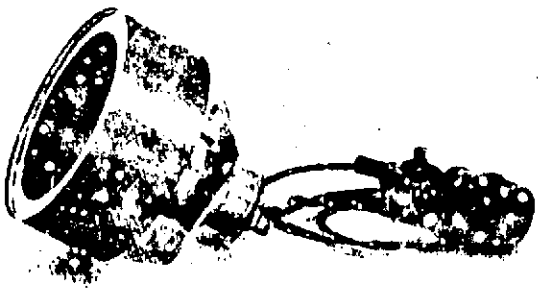

Fig. 9. Integral trap PL-40.

The RIP*-804 instrument is a triple ion spectrometer suitable for determining the position of the maximum of the energy distribution of the ion component of the plasma from the solar wind [9]. The instrument tracks the maximum with simultaneous measurement of the ion flux in three energy channels. The instrument serves for measurement of rapid fluctuations in plasma

* [Translator's note: Expansion not known.]

parameters, with a clearly pronounced maximum of energy distribution of ions as well as for determination of energy spectra of ions in the absence of such a maxima.

The spectrometer is composed of a sensor, measuring block and regulating block (Figure 11). The sensor is made in the form of three cylindrical electrostatic analyzers with various values of R_0/d (R_0 is the average radius of curvature, d is the distance between the plates), to whose plates a voltage is applied from one rectifier which detects 32 values over the 0-3.5 keV range. The average energy of the particles which are /21
passed by the electrostatic analyzer is proportional to the value R_0/d, so that with the same voltage on the plates the analyzers will pass ions with different values of average energy related to one another in the ratio 0.9:1:1.14. The ion currents on the

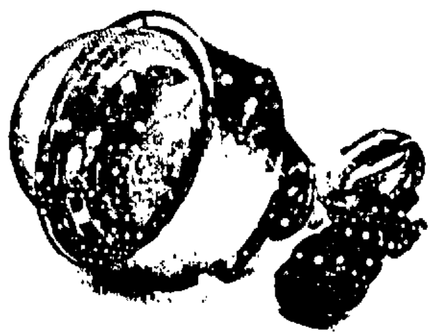

Fig. 10. Integral trap PL-46.

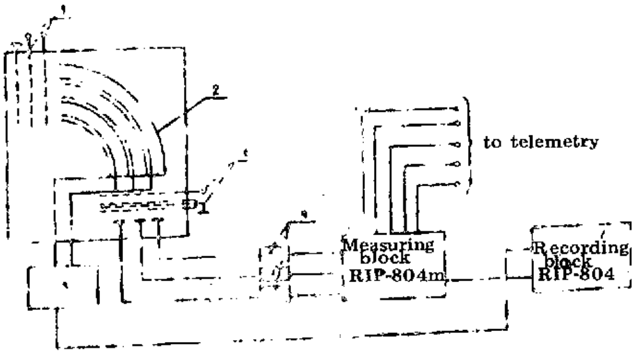

Fig. 11. Schematic diagram of the RIP-804 instrument. 1--screen grids; 2--analyzer plates; 3--stepped voltage generator; 4--detector block amplifier.

collectors of each of the three analyzers are amplified and converted in the measuring block into an analog voltage and sent to telemetry. Information on the magnitude of the current of each analyzer also enters the regulating block, which exercises control through a system of switching energy levels. The instrument operates in two modes: the "search" mode, in which the level of energy changes successively from minimum to maximum, and the "track" mode in which the value of energy E is automatically set at the maximum of energy distribution. The switch from the "search" mode to the "track" mode occurs with a simultaneous increase in the following values: the current in the circuit of the central collector with the value of $0.5 \times 10^{-11} \pm 50\%$, a ratio of the currents in the circuits of the collectors of the

central and [blurred] lateral analyzers with a value of 2^{+1}_{-0}
The switch to the "search" mode takes place automatically, but can also be executed on command from the ground. The range of measured ion current densities is from 2×10^6 to 2×10^{10} ions/cm^2·sec.

The RIP-803A instrument is intended for separating from the flux of plasma particles of hydrogen ions, the single-charged and double-charged ions of helium and measuring their energy spectra over the following energy ranges: H^+ ions in the 25 eV-4 keV range; HE^+ ions in the 100 eV - 8 keV range, He^{++} ions in the 200 eV - 16 keV range [10].

The spectrometer uses a combination of an electrostatic analyzer which selects charged particles on the basis of the E/q value (E= energy, q = charge) and a magnetic analyzer with a drift tube,/22 which transmits particles to the detector which have a set value P/q (Figure 12) (P is the momentum of the particles). The magnetic analyzer incorporates a permanent magnet of the sector type and a drift tube with an entrance window made of grating. The potential of the drift tube changes synchronously with the potential on the plates of the electrostatic analyzer in such a fashion that by inhibiting or accelerating the particles prior to their entrance into the magnetic analyzer, it can ensure the entry of the particles into the gap between the poles of the magnet at a given constant energy (for particles of different kinds this will differ).

The voltage on the analyzer plates and on the drift tube is switched synchronously with interrogation from telemetry, assuming sixteen different values for each specified type of particle, making it possible to measure their fluxes at 16 energetic points uniformly distributed over the indicated ranges.

The detector is a VEU* whose signals enter the measuring block and then go to telemetry. The measurement of these value of the flux can take place in two modes: in the mode of

* Secondary electron multiplier

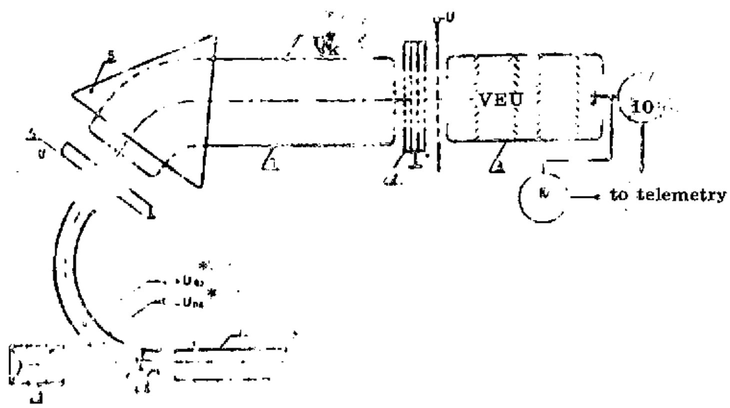

Fig. 12--Schematic diagram of the RIP-830A instrument. 1--collimator; 2--analyzer plates; 3--light trap; 4--diaphragm; 5--magnet; 6--drift tube; 7--screen grids; 8--VEU; 9--UPT†; 10--pulse recorder.

measurement of the counting rate, with loads up to 10^4 pulses per second, and in the mode for measurement of the DC above this level. The switching of the mode takes place automatically. The range of measurements of the flux density lies within the limit $\frac{10^4 10^9}{cm^2 sec}$ particles. The program of measurements of the spectrometer consists, of successive cycles of measurement of the spectra distributions of protons, HE^{++} ions, protons, HE^+ ions, and so forth. The indication of the number of the degree and the cycle of measurement is accomplished by pulsed voltage with frequency f of a telemetric synchronized pulse with recording of protons, 1/2f when recording HE^+ ions and 1/4f when recording HE^{++} ions.

*Illegible.

†Direct current amplifier.

Information on the magnitude of the measured flux is fed in in the form of an analog voltage.

The KYa*-4M instrument is a receiver for direct amplification and is intended for measurement of cosmic radiation. The range of detected signals lies in the area of wavelengths from 400 to 3000 m. For measurements at these frequencies, the "Prognoz" satellite was initially equipped with a frame antenna with an area of 1.8 m^2. In similar experiments, whip antennas were used. The frame antenna makes it possible to reduce significantly the level of shot noise and thereby increase the sensitivity of the receiver. The latter has four measuring channels, set to fixed frequencies of 100, 200, 350 and 700 kHz, an internal noise generator for callibration of the receiver during flight and a commutator controlled by synchronized pulse telemeters. The construction of the receiver is such that it is made in the form of one block located in the pressurized container. /23

The ANCh*-1 instrument is intended for studying the spectral intensity of the natural low-frequency of the electromagnetic field in the magnetosphere and the transitional region between the magnetosphere and interplanetary medium [11].

In order to study the very low frequency oscillations (VLFO), a receiving device is employed which operates over a frequency range from 1.6 to 8.0 kHz. The ANCh-1 instrument consists of a receiving circuit and a power circuit. The receiver contains: (a) input amplifier, (b) line amplifier, (c) spectral analyzers with discrete frequencies: 1.6; 2.5; 4.0; 6.3; 8.0 kHz (Figure 13). As an antenna, a magnetic frame is used with an effective area of 8 m^2. The sensitivity of the apparatus is $V_0 = 4.5 \times 10^{-6}$ gamma/Hz.

The SG†-59K instrument is a 3-component ferromagnetic magnatometer with an automatic measurement range expander (AR-1). The magnatometer is intended for measuring three components of a

* [Translator's note: Expansion not known.]

† Signal generator.

magnetic field within limits of ± 600 gamma for each component, with a revolution of one gamma. The instrument is composed of three blocks: (1) the sensor block, DSG*-59K; (2) the electronic block, ESG†-59K and (3) the automatic expander block, AR-1. /24

The sensor block contains three orthogonally oriented ferromagnetic probes, mounted in a common housing. The positive voltages of the ferromagnetic probes coincide with the axis of a regular rectangular system of coordinates. To cut down the influence of the magnetic field of the satellite, the block of sensors is mounted on a rod about 2 m long, whose tip is fastened to the external rib of the solar battery panel (Figure 2). The total distance of the sensor blocks from the housing of the satellite is about 4 m. The ESG-59K electronic block powers the ferromagnetic probes with an exciting current, amplification and conversion of the useful signal. The value of the voltage of the magnetic field is transformed into a constant voltage that changes from 0 to 6 volts with a change in the field voltage from 0 to 60 gamma. Information on the three components is transmitted on six telemetry channels: on channels X_1, Y_1, Z_1 the positive field is transmitted while the negative field is transmitted on X_2, Y_2 and Z_2 along the corresponding axes. The expansion of the limits of measurement of the field is carried out by means of an automatic expander AR-1. When the measured field is attained, for example along the X_1 channel with a value of +60 gamma, and the voltage in channel X_1 = +6 volts, the AR-1 block contains an automatic switch that operates in sending a strictly calibrated value of DC into the corresponding coil of the ferromagnetic probe. This current creates a field with a voltage of 90 gamma in the body of the ferromagnetic probe; the sign of this voltage is opposite to that which is measured. The voltage at the X_1 output drops to 0 and the voltage rises to 3 volts at the output of X_2, corresponding to the active field 60-90 = -30 gamma. With a further increase in the field the switch operates again. There

* [Translator's note: Expansion unkown.]

† electrostatic generator.

is a total of 6 ranges in the instrument for each component for positive and negative fields.

The number of the compensation range is given by three telemetry channels, YDX, YDY and YDZ. The block of sensors is fastened to the rod in such fashion that ferromagnetic probe "X" is directed with its positive end toward the sun, i.e., measuring the component of the field along the path of the rays from the sun. The "Y" and "Z" components are located in the plane of the solar batteries. Regardless of the distance of the sensor block from the housing of the satellite, the value of the corresponding field of the satellite in the volume of the sensors was significant. Zero readings determined on the basis of the results of the flight were X_0 = -4 gamma, Y_0 = +28 gamma, Z_0 = -25 gamma. /25

The OR*-1 instrument serves for the determination of the azimuthal position of the satellite in space (the angle of rotation of the satellite around its orientation axis "X"). The reflected light from the earth is used as the orientation point. The OR-1 instrument is composed of two sensors, OD*-1 and OD-2, which record the intensity of light from earth; two sensors SD-1 and SD-2, exposed to the light flux from the sun; a measuring block, "BIO", with two independent measuring channels and a power circuit.

The OD Sensor contains a photo-electron multiplier, FEU-58, with a signal amplifier (FEU) and a converter Pr*. The sensor is fastened to the cylindrical housing on which the flat columator with a visual angle of 148° x 2.5° is fastened.

The SD† sensor is structurally similar to the OD sensor but its columator has a visual angle of 170° x 10°, thus allowing proper switching of the mode of the OD when it enters the zone of visibility of the light flux from the sun. The sensitive

* [Translator's note: expansion not known.]

† Solar engine.

element of the SD sensor is a photoresistor. The current signal from the amplifier (U) of the sensor ODI* (or ODT*) is fed to the input of the electronic switch K-1 (Figure 14). The duration of the current signal t_3 is determined by the time the photomultiplier is illuminated. K-1 is closed for this period of time. Impulses from the generator (GI†) with a frequency s = 2 Hz ± 20% enter the input of the counting /26 circuit. The counting circuit stores the pulses for a time interval $t_{[illegible]}$ from the time half the illumination passes through until the arrival of the next synchronized impulse from telemetry. At the end of the pulse of light, switch K-1 closes and switch K-2, controlled by switch (KOM) opens. Then the pulses from the GI enter the counting circuit $t_{[illegible]}$. As soon the synchronized impulse raaches the KOM, it closes K-2. The input of pulses from GI to circuit $p_{[illegible]}$ ceases.

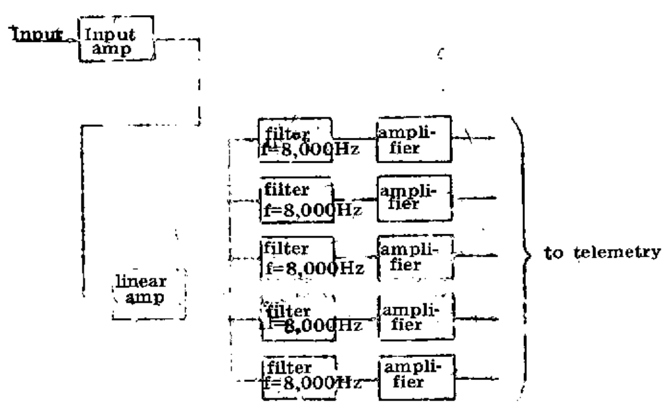

Fig. 13. Functional Diagram of the ANCh-1 instrument.

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* [Translator's note: expansion not known.]

† Pulse generator.

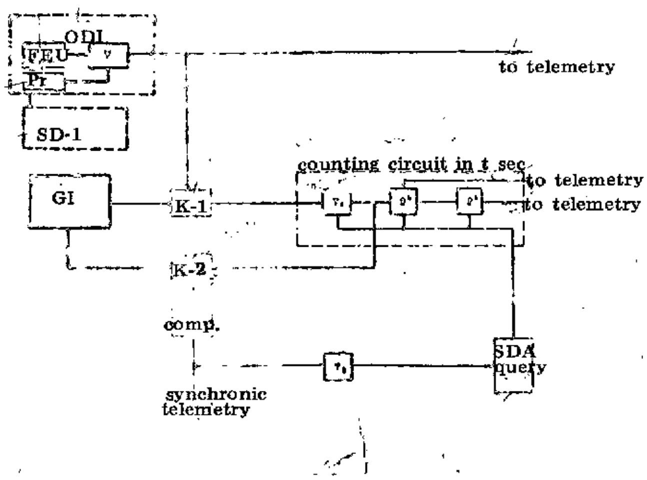

Fig. 14. Functional diagram of the OR-1 instrument. ODI-sensor of OR-1 instrument, FEU-photomultiplier FEU-58, GI-pulse generator, K-1, K-2 switch circuit, SDA-photodiode.

The voltage from the output of the counting, proportional in magnitude to the time t_{3c}, goes to telemetry. The synchronized pulse is also said to trigger T_2 and prepares it for passing the next synchronized pulse to the reset circuit. When the second synchronized pulse is received at trigger T2 and further at the reset circuit, a pulse is developed for zeroing the counting circuit. The counting circuit is interrogated twice in a row after the arrival of the first synchronized pulse and after the arrival of the next synchronized pulse.

The OR-2 instrument is intended for the measurement of the deviation of the lengthwise axis "X" of the satellite from the direction of the sun.

The range of measurements of the instrument times 70° is relative to the "Y" axis and the "Z" axis. Measurement accuracy is ±1.5°.

The OR-2 instrument consists of the ODS* sensor which has two mutually perpendicular columator targets, each of which is divided into fifteen optical channels and a power supply for the BP† ODS sensor. The visual angle of each optical channel is 2.5° times 50, the angle between the axes of adjacent optical channels is 1° x 20. With these geometric parameters of the columator, the total disc of the sun can be in the field of vision of only one optical channel. At the base of each of the fifteen optical channels of both slit columators are photoresistors which constitute receivers of solar radiation. When a photoresistor FS is illuminated, the signal from it goes to the threshold circuit (Figure 15). Since the measured resistances in the /27 circuit of each total resistance are different, depending on the level of the output signal, it is possible to draw conclusions regarding the number of photoresistors which are being illuminated by direct solar rays and thereby establish the deviation of the critical axis "X" of the satellite from the direction of the sun. Figure 16 shows a diagram of the arrangement of the sensors in the OR-1 and OR-2 instruments aboard the "Prognoz" satellite.

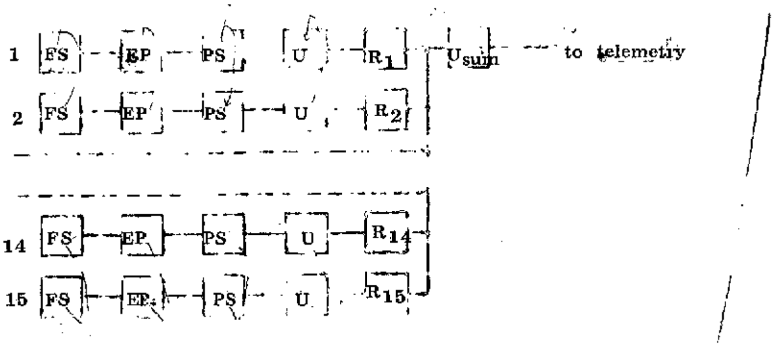

Fig. 15. Functional diagram of the OR-2 instrument. FS--photoresistors; EP--emitter repeater; PS--threshold circuit; U--amplifier; U_{sum}-summing amplifier; R_{1-15} measuring resistors.

* [Translator's note: expansion unknown.]

† Memory unit.

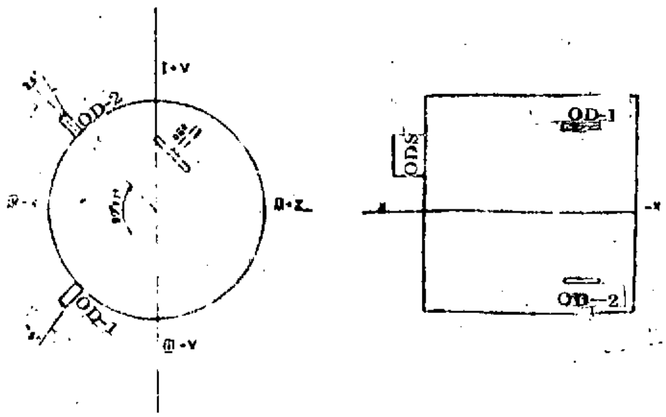

Fig. 16. Diagram of the location of sensors (OD and ODS) aboard the "Prognoz" satellite.

The "Prognoz-2" automatic satellite, in accordance with the program of Soviet-French cooperation, carries an apparatus for performing experiments to study the characteristics of the solar wind in the external regions of the magnetosphere (the "calypso" instrument), as well as the gamma radiation from the sun, and also a scanner for neutrons of solar origin (the "SNEG*-1" instrument). The "calypso" instrument is an electrostatic analyzer with a channeled electronic multiplier as detectors and intended for spectral measurements of the fluxes of electrons and ions in the energy range from 100 eV to 30 keV. The scintillation spectrometer "SNEG-1" is used to measure the spectra of gamma radiation in the energy range from 272 keV to 8.99 MeV as well as neutrons in a range from 0.98 to 16 MeV in 8 subranges.

3. Design and General Tests of Scientific Instruments.

Studies performed in space over a long period of time require

* [Translator's note: expansion not known.]

the development of a measuring apparatus that has a high degree of reliability. The apparatus in question can withstand considerable mechanical stresses without damage, retaining its working capacity during vibrations, and is not subject to problems resulting from pronounced changes in temperature or power supply.

Designwise, most of the instruments are made in the form of several blocks: blocks of detectors, mounted on the external surface of the satellite and an electronics block which is located inside the pressurized container. The external and internal blocks are connected by cables, passing through hermetically sealed junctions. /28

The design of these blocks is based on welded or sheet chassis made of duraluminum, on which the detector unit, necessary parts and elements of the circuits are mounted. The electronic circuits are made up of typical components installed on board using printed circuit techniques. These boards are assembled into individual plug-in units. In a number of instruments, modules that have been potted with phenolpolyurethane are used. All of the units mounted on the chassis are covered by all-enclosing covers or lids made of thin sheet duraluminum. The blocks are provided with technological and inter-block connections. The following are some examples of ingenious designs to solve problems involved in various parts of the assembly. Thus, Figure 17 shows a drawing of the assembly of the scintillation and Cherenkov detectors of the SEZ-2 instrument. This unit is designed so that it is easily removed from the instrument and can be tested separately before being installed on the device. The design of the MF-7 sensor (magnetic filter) of the RPZ* instrument is shown in Figure 18. The monolithic structure of chamber "A" (Figure 19) is in the form of a sphere made of lucite, connected by threads to the base. Inside the base is an electrostatic relay which is composed of a thin platinum-silver wire attached to the edge of a

* [Translator's note: expansion not known.]

rotating disc. By rotating the disc, it is possible to regulate the gap between the thread and the contact. The electric relay periodically "pulls off" the thread, which can become welded to the gold-plated contacts when it comes in contact with it. At the center of the sphere, on a bushing made of amber, is the collecting electrode.

Table 3 shows some of the data on the chambers that were built. Figure 20 shows an outline of the interrogating switch OKM-2 with 24 positions, used in the IK-2P instrument. Tests have shown that this design can withstand more than 500,000 operations without failing.

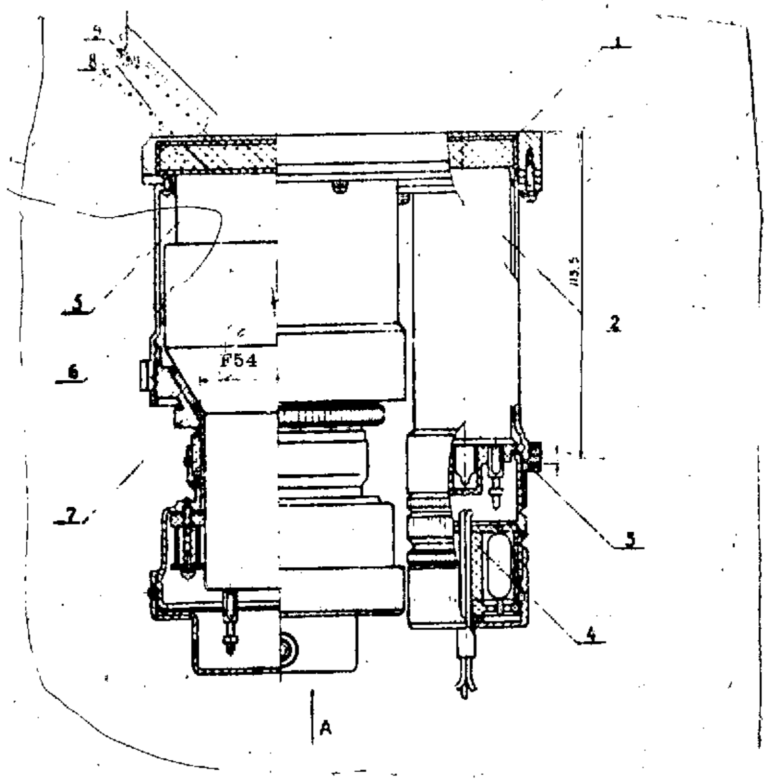

Fig. 17. Diagram of the Cherenkov and Scintillation Detectors of the SEZ-2 Device. 1--plastic scintillator; 2--FEU-16 photomultiplier; 3--photomultiplier panel; 4--divisor; 5--Cherenkov radiator; 6--FEU-56 photomultiplier; 7--housing of the unit; 8--light shield; 9--gasket.

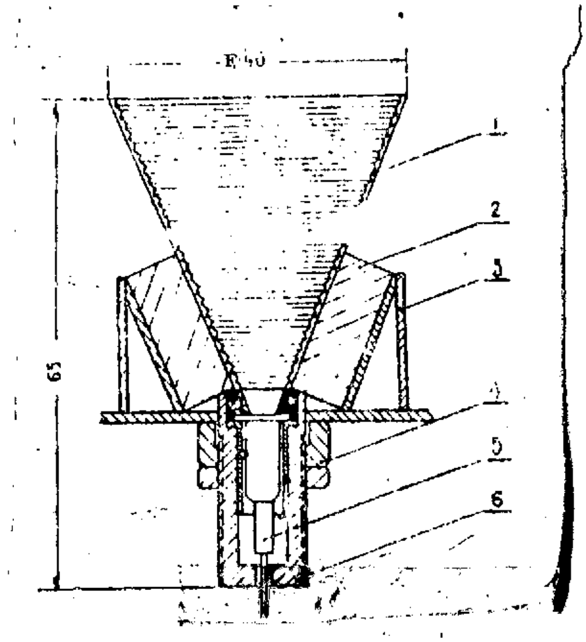

Fig. 18. MF-7 Sensor (magnetic filter) of the RPZ instrument: 1--input columator; 2--magnet; 3--housing; 4--nut; 5--gas-discharge counter STD-18.

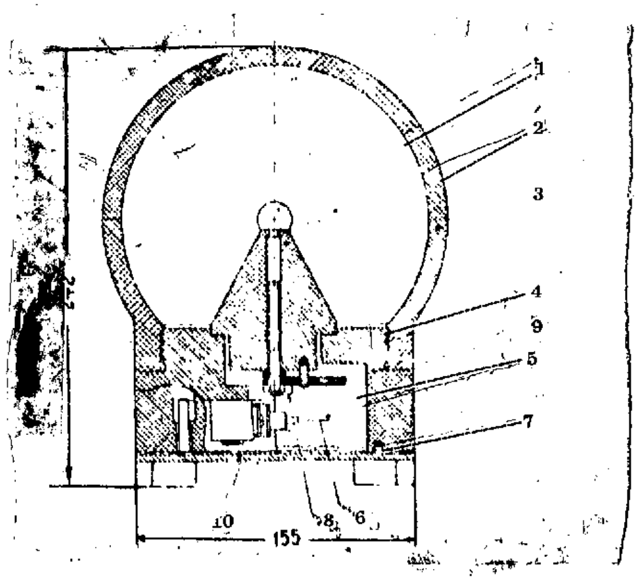

Fig. 19. Ionization chamber of the IK-2P instrument. 1--selecting electrode; 2--amber insulator; 3--spherical housing of the chamber; 4--connection; 5--base; 6--gold plated contact; 7--covering; 8--wire; 9--output; 10--lid.

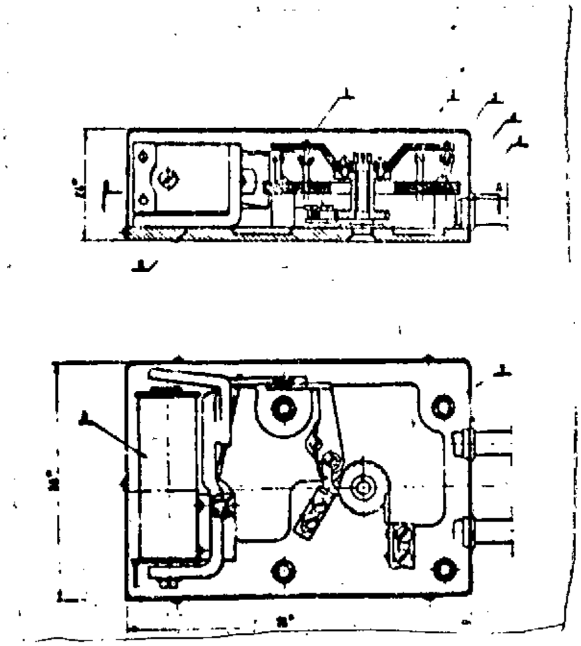

Fig. 20. Interrogation switch OKM-2. 1--housing; 2--moving system; 3--contact group; 4--plate; 5--output leads; 6--base; 7--fastening opening; 8--electromagnet.

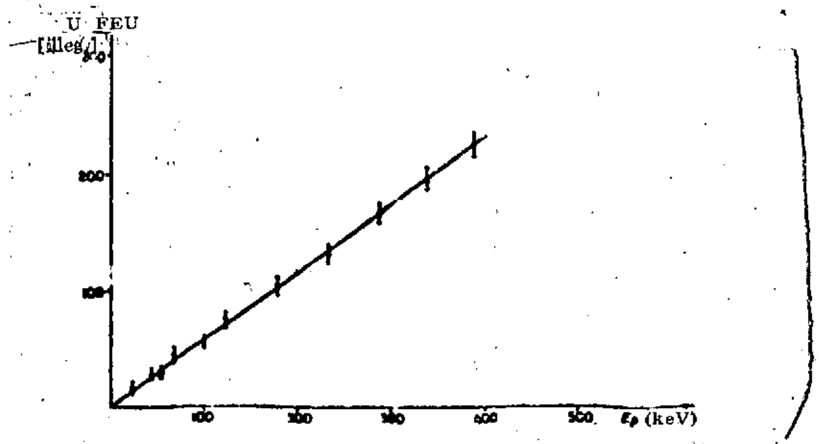

Fig. 21. Output amplitude of detector signal of SA-2 instrument versus proton energy.

To have reliable operation of scientific apparatus at the /29 stage of manufacture and assembly the elements of the electrical system are carefully chosen. Semiconductor devices pass through a cycle of accelerated "aging" in order to increase the stability of their parameters.

The instruments are tested in many ways under conditions which are as close to the maximum operating conditions as possible. Mechanical, climatic, electrical and resource tests are performed. The apparatus is held in the on position for 200-300 hours to reveal any latent defects.

Mechanical tests were performed as follows:

a) Vibration loads

Acceleration g	Frequency range Hz	Testing time sec	
0.7	3-17	150	Instruments tested in three mutually perpendicular axes
1.2	17-30	150	
3	30-100	200	
5	100-300	600	
8	300-1200	600	
12	1200-2500	750	

b) Linear stresses--magnitude of acceleration reached 12 g for 15 minutes.

Climatic tests involved checking the faultless operation of instruments with variations in the temperature of the environment:

From -20 to +45°C, for the output blocks;

From 0 to +40°C for those blocks that were mounted in the pressurized container.

The working capacity of the instruments was tested under relative hermetic conditions up to 85% as well as under vacuum conditions.

Table 3. Several Parameters of the Ionization Chambers

No. of Chamber	Type "A" of Chamber					Type "B" of Chamber				
	1	2	3	5	6	1	3	4	5	2
Working Capacity, cm^3	260	250	252	254	250	70	68	64	69	70
Thickness of Covering, microns	0.69	0.63	0.72	0.7	-	0.75	0.82	0.61	0.79	-
Working Pressure, atm	10	10	10	10	-	1	1	1	1	-
Rupture Pressure, atm	-	-	-	-	51	-	-	-	-	65

/30

Electrical tests were performed to test the quality of the electrical assembly, the resistance of the insulation, the current carrying devices, the threshold levels for operation of the discriminators, the output voltages and the resistances of the adders and ratemeters, the resolution time of the circuits and so forth under all of the climatic and mechanical influences listed above. Tables 4 and 5, for example, show the results of tests of the type TS* adder and the logarithmic ratemeter, type I-2. /31

As we can see from Table 4, the intervals between individual levels of voltage vary from 0.35 to 0.6 volts, making it possible to identify each step of the adder reliably.

The area of linearity of the logarithmic relationship $U_{out} = k \log N$ (for 0°C) (Table 5) is betwen 6.3 and 250 impulses per second. In this range, the voltage varies from 1 to 4.7 volts. In the range from 2 to 6.3 impulses per second and from 250 to 1000 impulses per second there is nonlinearity and a deteriorating measurement accuracy. The temperature instability in the four impulse per second range is $\pm$0.12 volts, and $\pm$0.2 volts in the 1000 impulses per second range. The data presented in Table 5 were obtained during testing of the ratemeter circuit of the period pulse generator. In calibrating the ratemeter with statistically distributed pulses, there is a shift in the output characteristic. When the scientific information is being processed this shift is taken particularly into account. /32

To check the working capacity of the instruments independently, as well as during testing in combination with other instruments and auxiliary systems aboard the satellite, a special control panel was devised for each instrument. These panels made it possible to check rapidly the operation of the electronics and the automatic elements of the instruments: the threshold level of

* [Translator's note: expansion unknown.]

Table 4

Results of Climatic Tests of Type "TS" Adder

No. of steps	Permissible Values, Volts	Measured Values, Volts		
		at +40°C	at +20°C	At 0°C
0	0-0.2	0.1	0.12	0.1
1	0.7-0.95	0.79	0.79	0.72
2	1.35-1.65	1.49	1.51	1.50
3	2.0 -2.45	2.22	2.21	2.20
4	2.8 -3.2	3.16	3.12	3.09
5	3.75-4.15	3.95	3.91	3.89
6	4.65-5.05	4.8	4.82	4.8
7	5.55-5.95	5.71	5.65	5.63

Table 5

Results of Climatic Tests of the Logarithmic Ratemeter

Number of Impulses per second (generator)	1	4	16	64	124	512	1000
Out							
at 0°C	0.05	0.6	1.9	3.3	4.0	5.15	5.5
at +40°C	0.1	0.85	2.1	3.5	4.25	5.5	5.9

discriminators, the operation of the counting registers, non-logarithmic ratemeters, coincidence and noncoincidence circuits, internal commutators, and so forth.

4. Adjustment and Calibration of Scientific Instruments. /33

As we can see from section 2, the scientific apparatus mounted aboard the "Prognoz" satellite was intended for measurements of solar and galactic radiation over a wide energy range (Tables 1, 2), with emission of certain types of radiation: electrons, ions, protons, alpha particles, atomic nucleii, electromagnetic, x-ray, and gamma radiation. To solve this problem it is necessary to have a comprehensive check of the physical characteristics of the scientific instruments. Correct adjustment and calibration of the instruments will make it possible to achieve a transition from the instrument readings (for example from the number of pulses per second) to the radiation flux in a specific energy range (ΔE) and the sampling angle of radiation (α). In laboratory experiments, the physical characteristics were determined experimentally (geometric factor G), recording efficiency (ε), energy threshold of recording (E_{thresh}), position of energy slots of the instrument (ΔE), angular characteristics. In those cases where the experimental checks were complicated, calculation methods were used for determining the characteristics of the detectors. Particular attention was devoted to the energy callibration of the instruments, since the spectrum of the detected radiation has a degree-dependence upon the energy $n(E) = n_0 E^{-\gamma}$, where $\gamma>1$.

In the following, using concrete examples, we will discuss the order of calibration of the instruments.

Some of the detectors that go to make up the apparatus in question (Table 1) are scintillation and semiconductor receivers of radiation and have spectrometric properties. Some instruments are spectrometers (for example, the RPZ, D140, RIP, RF-1, SGL-1, and others). These characteristics of the detectors make it possible to determine exactly the energy interval (ΔE) in which radiation is recorded and to plot the corresponding energy threshold (E_{thresh}). In checking the detectors, appropriate /34 radiation was selected: α-particles, radioactive sources of "X" and gamma radiation. The measurements were performed both separately with sensors and directly using the electronics in the instrument.

The low energy proton detector, made of CsI(Tl) with a thickness of 100 microns, the SA-2 instrument, was checked using the KG*-500 cascade proton accelerator of the NIIYaF MGU†; the energy of the beam varied from 25 to 400 keV. As we can see from Figure 21, there is a linear relationship between the amplitude of the FEU impulses and the proton energy striking the crystal. Figure 22 shows the amplitude spectrum of the detector impulses for protons having energy of 200 keV. The curve b shows the effect of the threshold set at an energy of 200 keV.

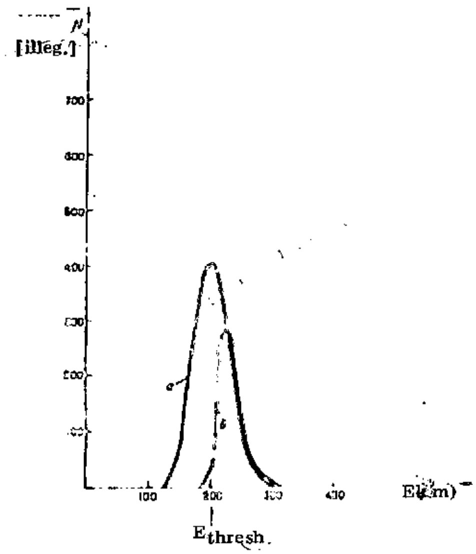

Fig. 22. Amplitude spectrum of impulses of the detector of the SA-2 instrument (a) for protons with E_r = 200 keV; (b) for protons with E_{thresh} = 200 keV.

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* [Translator's note: expansion unknown.]

† Scientific Research Institute of Nuclear Physics of Moscow State University.

The detectors of the SEZ-3 instrument were calibrated using a radioactive source of α-radiation (Pu^{239} and Th^{228}) the energy in MeV is shown in Figure 23, while the thickness of the semiconductor detectors was 50 microns. The energy scale (B), converted into amplitudes of impulses from the generator (U), is shown in the same figure. The energy distribution of the Si detectors used in this work is on the order of η = 3% at an energy of 5-9 MeV. The telescope composed of silicon detectors in the SEZ-3 instrument was tested on the cyclotron of the Moscow State University Scientific Research Institute Nuclear Physics. The protons of required energies developed in the reaction $C^{12}(\alpha, r)$ and struck the telescope, where they caused coincidences in two silicon counters and were absorbed in an absorber ahead of the third detector (Figure 24). In the input detector D1 of the telescope, in the reaction spectrum C^{12} (α, r), individual energy groups of protons resolved by the telescope were separated. Figure 24 shows the spectrum of the impulses measured in the input detector E'_{in}, caused by protons of the groups P_0 followed by C^{12} (α, r_0). The released energy, on the order of 1.5-2 MeV, agrees with the calibration of the α-sources. The Si telescope /35
also was checked using a beam of α-particles with E_α = 25 MeV, subjected to angular scattering on gold foil at 60°. The released energies in the input detector are in the 12 MeV range. Their telescope reliably separates protons and alpha particles.

The Cherenkov detector, the SEZ-2 instrument, was checked using cosmic radiation. Figure 25 shows the spectrum of electrical impulses from the muons that was obtained in the laboratory after five hours of measurement. As we can see from the figure, the resolution of the instruments for singly charged relativistic particles is on the order of 50%. The figure contains an arrow showing the threshold of the instrument,

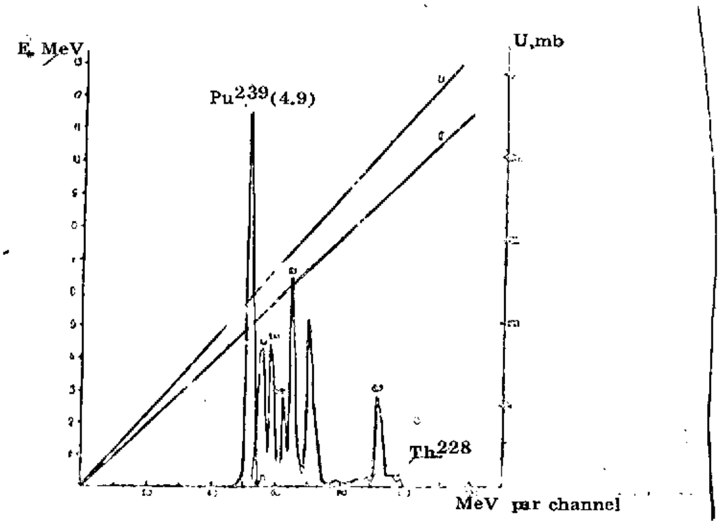

Fig. 23. Spectra of sources Pu^{239} and Th^{228}, measured with a silicon detector 50 microns thick.

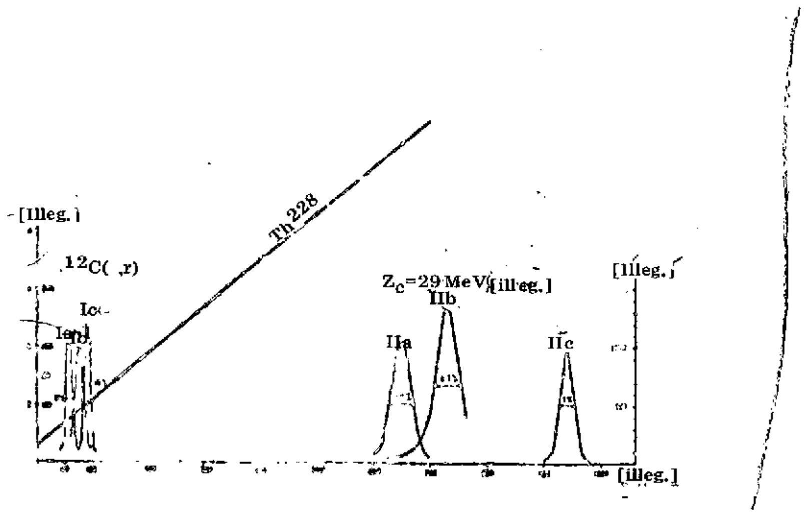

Fig. 24. Spectrum of impulses in input detector of silicon telescope. Ia--without absorber; b--with absorber 10; c--with absorber 16; IIa with absorber 30; b--without absorber; c--with absorber 20.

U_{thresh} = 15 mV for particles with a charge Z equal to or greater than 1 and U_{thresh} = 100 mV for Z equal to or greater than 2. As measurements with cosmic rays have shown, the amplitude of the impulses for singly charged particles received by the instrument in the reverse direction from its input aperture is approximately 20 times less than the impulses from the same particles passing through the input aperture. Electrical thresholds were established in the instrument for the recording of particles with a charge equal to or greater than 2.

The magnetic spectrometers of the RPZ instrument (Table 1) was calibrated in a lens-type β-spectrometer. In Figure 26 (curve a) we can see a portion of the spectrum of the electrons from Cs^{137}, measured with a lens-type spectrometer and a gas-discharge counter (SBT-18) used as the electron receiver. At the bottom (curve b) are the readings of a spectrometer located at the position of the gas-discharge counter. The instrument cuts a small part out of the entire electron spectrum: its energy revolution is on the order of 25-30%.

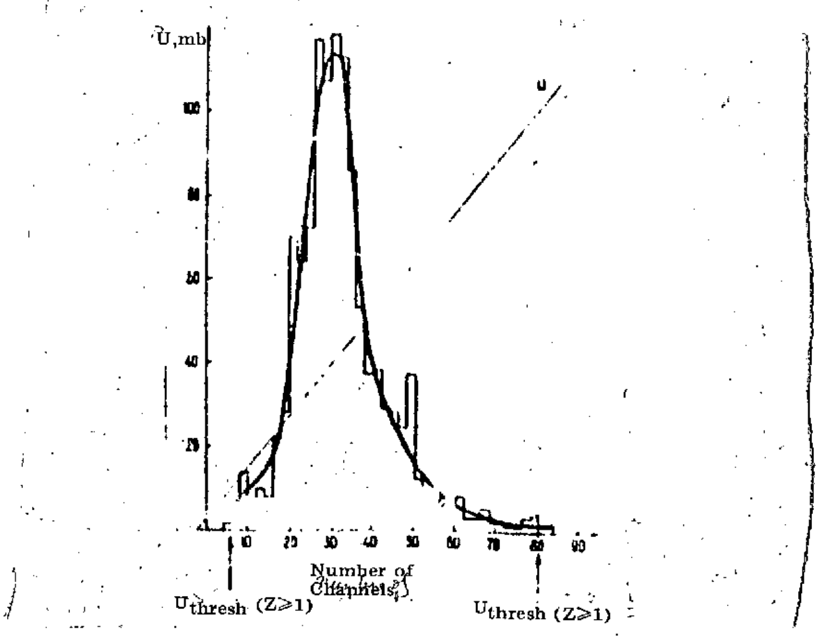

Fig. 25. Spectrum of μ mesons measured with the SEZ-2 instrument.

The calibration of the RS-1 and SGL-1 instruments was conducted by means of radioactive sources. Figure 27 shows the spectra that were measured with the proportional X-radiation counter, using Co^{57} (6.4 keV, 14 keV), Sn^{119} (24.4 keV) and the fluorescent d-radiation of lead. As we can see from the figure, the proportional counter of the RS-1 instrument has satisfactory energy resolution. The gamma spectrometer /36
with the CsI(Tl) crystal was checked by means of radioactive sources: Sn^{119}(24 keV), Hg^{203}(72 and 279 keV), Co^{57} (129 keV) and Cs^{137}(662 keV) in a similar fashion. The apparatus developed for the recording of electromagnetic radiation makes it possible to check the measurement of the spectrum within selected energy ranges.

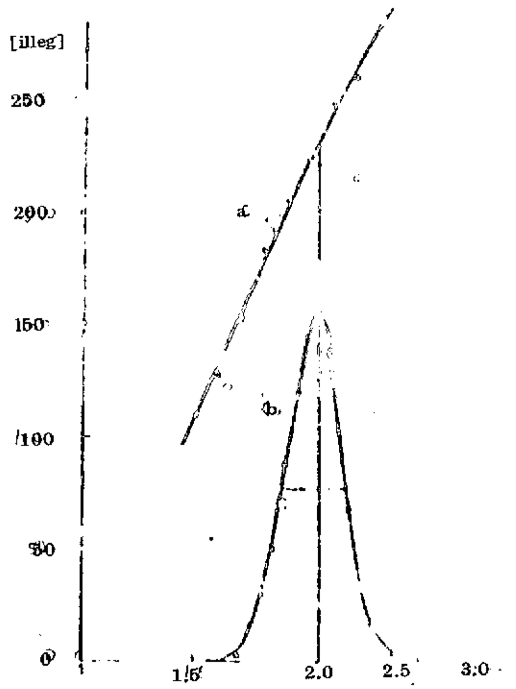

Fig. 26. Spectral characteristic of magnetic spectrometer of the RPZ instrument obtained by means of the β-spectrometer.

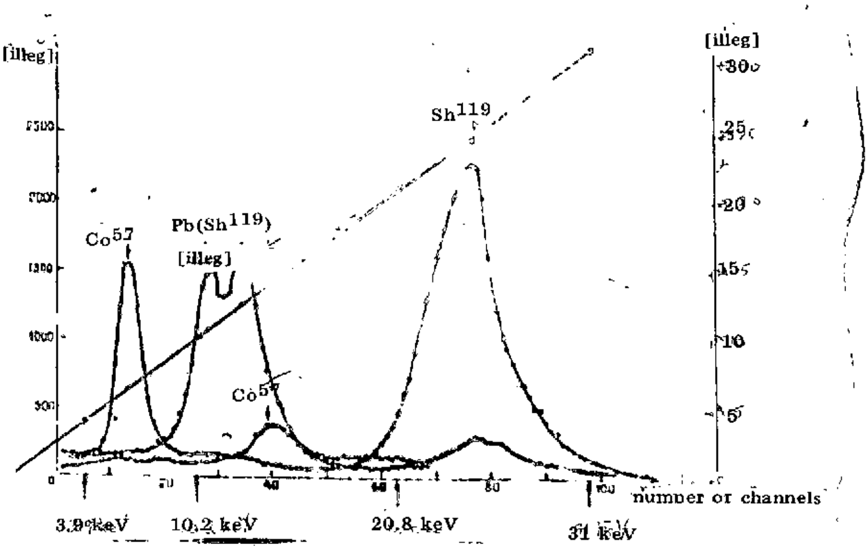

Fig. 27. Calibration curve of X-ray spectrometer.

The angular and energy characteristics of the modulated traps PL*-18 of the D-140 instrument (Table 2) were studied in detail in the laboratory using a special vacuum device while irradiating them with a broad parallel beam of ions. Each example of the trap was calibrated using a vacuum device jointly with the electronics block which made it possible to obtain the physical characteristics of the specific traps.

The number of recorded impulses N makes it possible to convert to the flux n of primary radiation if we know the efficiency of recording (ε) and the geometric factor of the instrument (G).

The recording efficiency of the protons by means of semiconductor defectors is nearly 100%.

*[Translator's note: Expansion unknown.]

In the measurements of the electromagnetic radiation, calculation requires consideration of the absorption of radiation along the path to the detector and the probability of absorption of the detected radiation in the effective volume of the detector--gas of the proportional counter of the crystal of CsI(Tl). Figures 28 and 29 show the results of calculations of the efficiency of instruments RS-1 and SGL-1.

In the case of magnetic systems of the RPZ instrument, their transmission was studied. According to Figure 26 type data, we found that part of the β-spectrum of Cs^{137} which falls into the interval isolated by the spectrometer. It was found that in the case of magnetic filters (RPZ instrument), in which the difference in calculation of two sensors gives the desired flux of electrons, the coefficients of transmission for the energy of electrons below 500 keV does not exceed 1%, and is 4% at 1 MeV.

The electron recording efficiency of the counter with magnetic filtration is on the order of 99-95% (the above-mentioned difference in response has been kept in mind). /37

In the ionization chambers of the IK-2p instrument, we carefully studied the background reading, determined the limiting dose of the linear characteristic of the chamber and the dose of radiation in one step. The calibration of the ionization chambers was carried out by means of a thoriated source, Ra^{226} (5.88 mg) in good geometry. The accuracy of calibration was a minimum of 10%.

The aperture angle (α) of the detectors fitted with columators was determined experimentally. For example, Figure 30 shows the experimental angular diagram for the electron detectors with magnetic filters. In some cases α and Γ were calculated on the basis of the detector geometry.

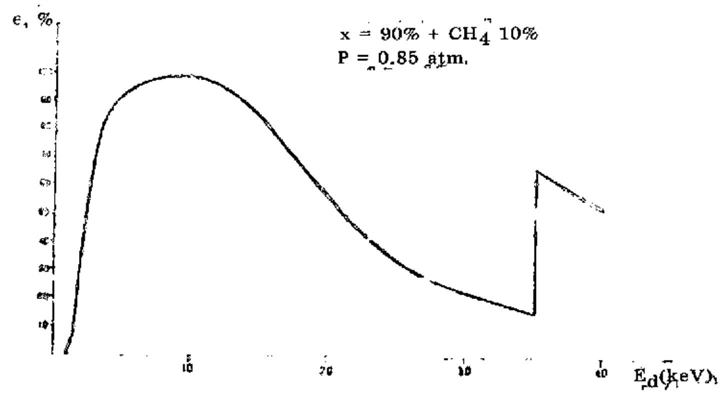

Fig. 28. Calculated efficiency of the RS-1 instrument for recording X-rays.

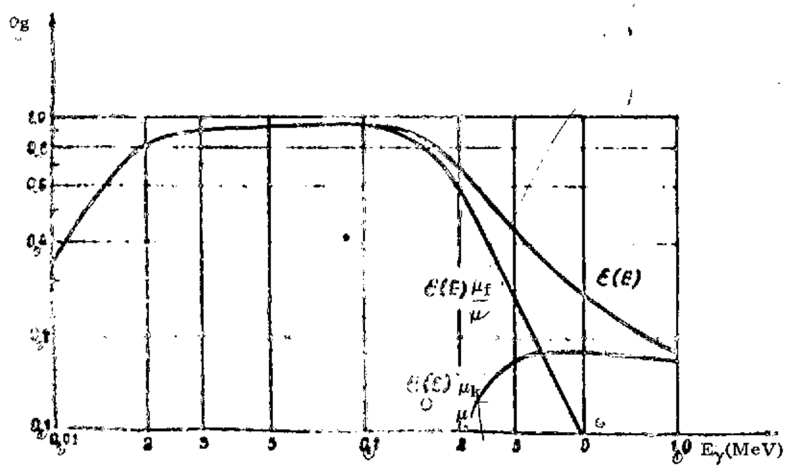

Fig. 29. Calculated efficiency of the SGL-1 instrument for recording gamma radiation.

Calibration of the optical sensors of the OR-2 instrument was carried out on the basis of the sun in the Crimea, in the village of Nauchnyy.

The voltage at the output of the instrument was linked to the number of the illuminated diodes by the relationship $\frac{5.5 + 0.5}{15} \cdot (n \pm 0.4)$, where n in the number of photo diodes.

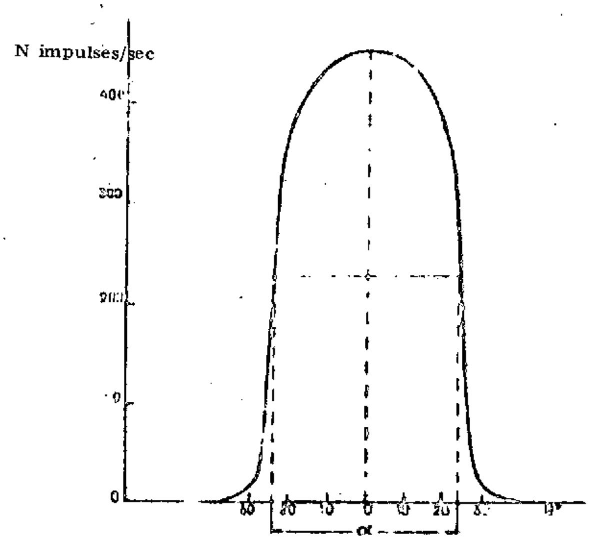

Fig. 30. Angular diagram of the magnetic "filter" of the RPZ instrument.

TABLE 6. Angular Dimensions of the Response Bands of the OR-2 Instrument Sensors and of the Intermediate Dead Bands.

Number of Sensors	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Angular Dimension of Response Band	50'	1°4'	54'	1°4'	1°5'	1°6'	1°	1°6'	59'	1°12'	1°4'	56'	1°7'	1°3'	1°
Angular Dimension of the Insensitivity Band	16'	20'	22'	16'	15'	16'	16'	22'	10'	14'	16'	22'	15'	22'	--

As we mentioned earlier, it is possible when recording the particles to have errors associated with the dead time of the recording system, including the receivers of radiation and the electronic components. Therefore under laboratory conditions we studied the so-called overload characteristic of the instrument. The intensity of the radiation was changed by moving the radioactive source. Such checks were carried out with ionized radiation sensors that formed part of the equipment in question. No systems were approved that had a drop in the counting time after the saturation portion. /37

5. Method of Testing the Complexes of Scientific Instruments. /39

Fifteen scientific instruments mounted aboard the satellite and connected with the radio telemetric apparatus, onboard power source, and automatic systems of the satellite constitute a complex electrical unit requiring careful checking. Table 7 lists the tests that were performed with the scientific instruments, the order of these tests, and the problems that were solved at each stage.

Table 7

Number of Tests	Type of Tests	Goal of the Tests
1	Autonomous checking of each instrument prior to installation aboard the satellite.	Checking the retention of of working capacity of the instrument after storage and transportation.
II	Autonomous checking of the system of scientific instruments from the control panel (PU7K)	Checking the working capacity of the combination of scientific instruments linked together by the onboard cable harness.
III	Autonomous recording of the parameters of the scientific instruments on the TM system with power and control from the control panel (PU7K)	Checking joint operation of the combination of scientific instruments and the TM-system.

Table 7 (continued)

IV	Tests with a scientific apparatus jointly with all satellite systems	Checking the joint operation of the combination of scientific instruments and all satellite systems.

I) Each instrument was tested independently, using the appropriate control panel, prior to its installation aboard the satellite. The blocks of detectors and the electronics were tested and connected to the control panel by means of test wiring. The tests were carried out according to certain programs that had been developed for each instrument. Such a check excluded first of all the arbitrary evaluation of the working capacity of the instruments and secondly it considerably shortened the testing time. The test programs were designed to include a detailed check of the listed memory lines, the methods of operation of the electronic elements, the stability of the internal commutator cycles, the levels of the thresholds of the discriminators, accuracy of switching of various modes of operation of the instruments, calibration of the intensimeters, and so forth. The working capacity of the sensors recording the ionizing radiation was checked by means of radioactive compounds, while the optical sensors were checked by appropriate light sources and the radio receivers were checked with standard signal generators. /40

II) The blocks of instruments installed on the satellite were connected with each other and with intermediate switching blocks 7K through the onboard cable harness. During the manufacture of the instruments, the detector and electronics blocks were connected by

test wiring whose parameters, of course, were different from the actual onboard cable harness. The onboard wiring emerged /41
through sealed openings; the braided shielding on the cables was connected with the housing of the satellite at several points, and in various types of tests extension cords were used, and so forth. All of this could promote the development of undesirable short circuits, mutual inteference, and adjustment. The satellite was equipped with a great many complicated electronic devices and automatic systems. Therefore, before connecting the scientific instruments to the service systems of the satellite, they were tested separately, using only the onboard cable harness. For these tests, a special control panel was devised called PU*7K which made it possible to supply the instrument complex with 27 volts and also to simulate any onboard commands and operating modes of the scientific instruments. The control panel contains a generator that forms synchronous pulses at a frequency of one pulse per second and 1/41 impulses per second (rapid and slow interrogation modes). Three meters on the panel show simultaneously the three output parameters of the instrument. It is possible to record the output parameters on strip chart recorders. Figure 31 shows a simplified block diagram of the scientific instruments and the control-testing equipment used in this type of test. The tests were performed according to a special program which made provision for detailed successive checking of scientific instruments. In each instrument we checked the correctness of the output of measured parameters for telemetry in the block 7K, the response of the electronic parts to control commands, constancy of the switching cycle in those instruments where there was one, and execution of various control commands.

III) The next stage in testing consisted in the independent recording of the scientific parameters via telemetry. As in the /42

*Switching device

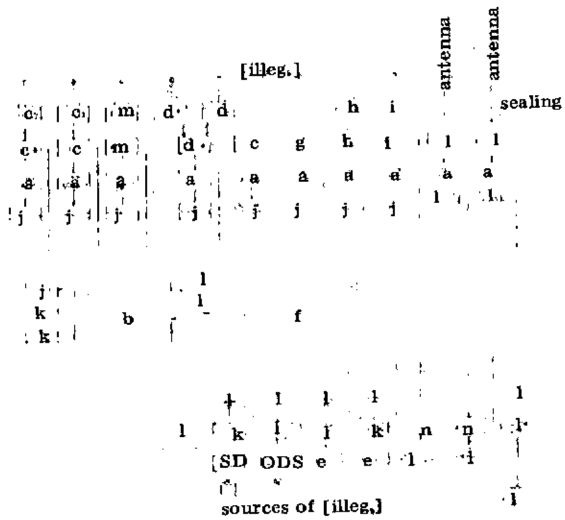

Fig. 31. Block diagram of the assembly of scientific devices and control-testing equipment. a--panel test; b--control panel and testing of PU7K; c--SEZ-3b; d--SD-2b; e--RID*801; f--[illeg.] for adjusting the scientific instruments of the PU-7K apparatus; g--MK-2P; h--SGL-1b; i--RS-1b; j--recording instrument; k--auxiliary power supply; l--illegible; m--RPZ-b; n--D-125U.

previous type of testing, the entire assembly was connected through the PU7K panel and checked. Recordings via telemetry indicated the following:

a) Correctness of choice of recorded parameters of the open circuit of the telemetry instrument;

b) Synchronization of the scientific apparatus from telemetry;

c) Recording of the calibration frequencies for calibration of the output systems of the instruments.

Figure 32 shows the curve of the ratemeter plotted as a dashed line on the basis of the data from the control telemetric recording. Similar corrections were made in the calibration of all the instruments.

IV) Following independent recording of the scientific parameters via telemetry, the control panel of the PU7K was disconnected,

* Radioisotopic engine

the power and control of the scientific instruments were switched over to the onboard systems of the satellite. The satellite was finally ready. The last recording of scientific parameters by telemetry was carried out, checking the functioning of the apparatus in all operating modes. The working capacity of the instruments which measured the electromagnetic radiation and the charged particles were checked by means of selected radioactive sources and signal generators. The optical devices were checked by special light sources.

6. Operation of Scientific Apparatus during Flight. /43

To evaluate the working capacity of the scientific apparatus during flight, an analysis of the data received during the communications session with the "Prognoz" station was used when it was about 32,000 kilometers distant (April 14, 1972) and during the communications session when the station was at a distance of 190,000 kilometers from Earth (April 15, 1972). From the information that was obtained on these two communications sessions, the working capacity of the scientific apparatus during the flight was evaluated and the shapes of the radiation belts of the Earth were measured, the limits of the magnetosphere and the transitional region, the emergence of the Prognoz station beyond the short wave front was determined, etc. All parameters were measured including the magnetic field. The parameters of the solar wind, the components of the cosmic radiation were studied and the radiation situation along the path covered by the station was evaluated.

The following are some characteristic examples of the readings of the scientific instruments which qualitatively illustrate their functioning in the form of the primary scientific information.

Figure 33 shows the readings of semiconductor detectors for protons and alpha particles in the SEZ-3 instrument (with some arbitrary averaging), obtained in the course of two days of flight by the satellite beyond the limits of the magnetosphere while observing the fluxes of protons at low energies. The observed difference in the counting rates of the detectors that were measuring protons were E = 1-47 MeV from the solar and reverse direction, indicating an isotropy of the primary flux. An increase in the counting rate of the proton detector with E = 14-35 MeV was insignificant. Figure 34 shows the nature of the information from the electron detectors in the SA-2 instrument when the satellite was moving within the magnestosphere but outside the radiation belts. As we already mentioned, the primary flux of particles is determined from the difference between the readings of these two detectors.

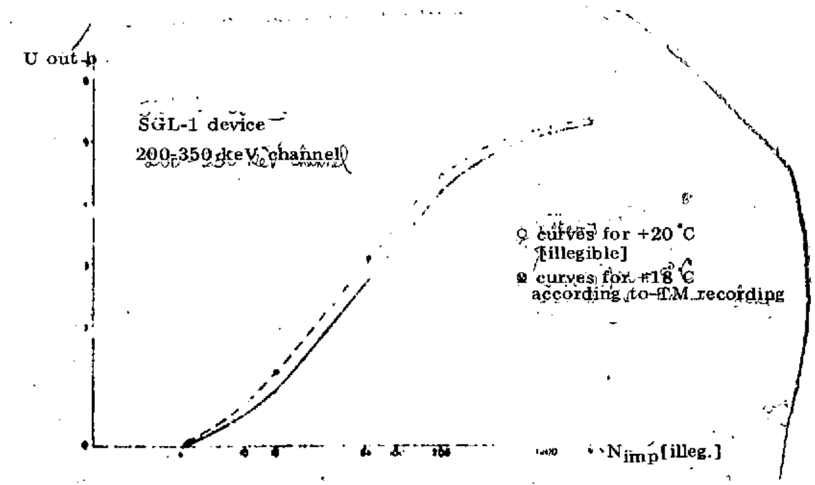

Fig. 32. Output characteristic of intensimeter plotted in the course of the independent check and during the TM recording.

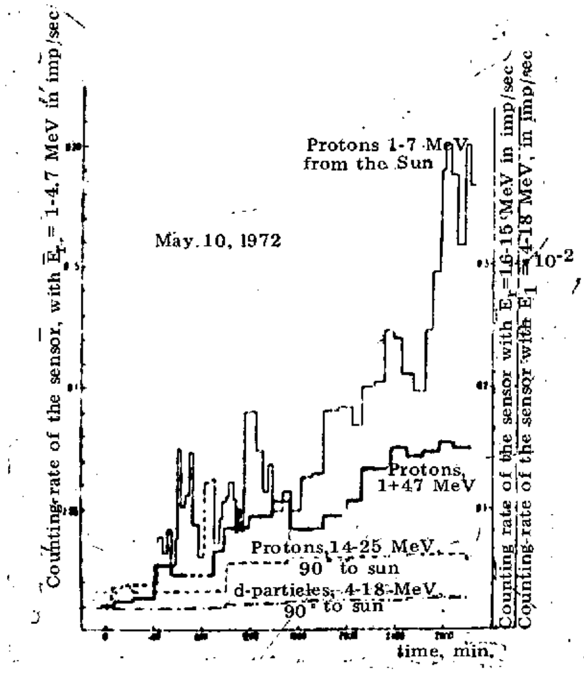

Fig. 33. Sample of information obtained from semiconductor detectors aboard the SEZ-3 instrument in interplanetary space on May 10, 1972.

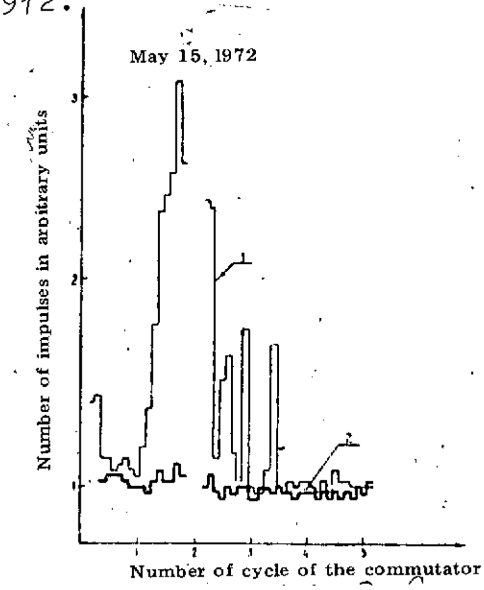

Fig. 34. Counting rate of impulses from gas-discharge counters of the SA-2 instrument. 1--counter without magnetic field; 2--counter with magnetic field.

The counting rates of the gas discharge counters of the RPZ instrument with magnetic filters are shown in Figure 35. Here the considerable increase in the counting rate of one of the detectors was caused by the passage of the satellite through the magnetosphere. The change in the counting rate of the gas discharge counter of the magnetic spectrometer was $E_{e^-} = 40$ keV, for that area of space, shown in Figure 36. /44

Figures 37 and 38 illustrate the functioning of the RS-1 and SGL-1 instruments when passing through the region of the radiation belts of the Earth.

A characteristic recording of one of the parameters of the ANCh instrument (frequency channel--8,000 Hz), obtained when the satellite was 65,000 kilometers distant, is shown in Figure 39.

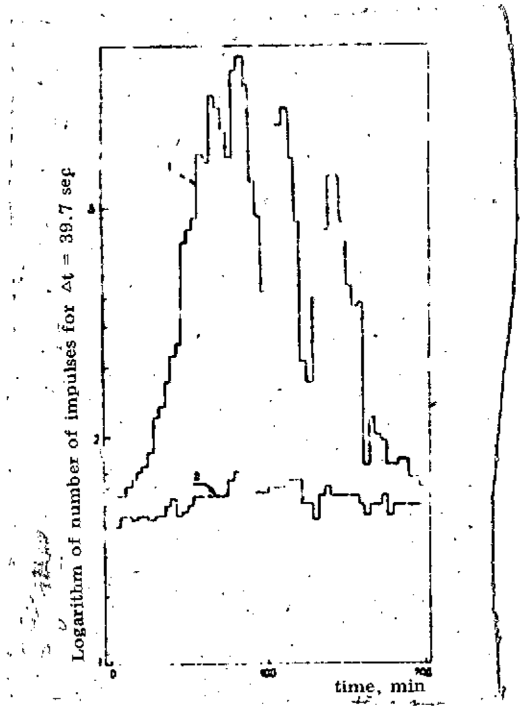

Fig. 35. Histogram of counting rate of gas discharge counters of the RPZ instrument: 1--counter without magnetic field, ($E_{e^-} \gg 30$ KeV, $E_{e^-} > 500$ KeV); 2--counter with magnetic field, $E_{e^-} > 400$ KeV, $E_{e^-} > 500$ KeV).

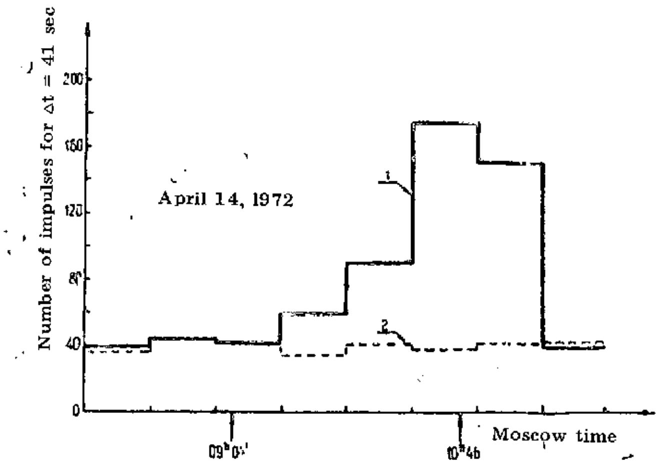

Fig. 36. Counting rate of magnetic spectrometer with E_{e}^{-} = 40 keV, oriented at an angle of 90° to the X axis of the satellite: 1--readings of magnetic spectrometer; 2--counting rate of the "background" spectrometer.

Typical spectra of the plasma, measured by the modulation trap (PL-18) of the D-140 instrument, are shown in Figure 40. It must be kept in mind that in this form these spectra are not an exact representation of the true distribution of the ions by energies, but are rather complicatedly linked to it. Nevertheless, the qualitative difference in spectra (a) and (b) indicates a sharp narrowing of the energy spectrum of ions when a satellite leaves the transitional zone (spectrum a) and enters interplanetary medium (spectra b and c). Spectra b and c are typical of solar wind, the second peak occurring at a higher energy in spectrum (c) and usually being attributed to doubly ionized atoms of helium. An example of the recording of the current from the PL-40 trap

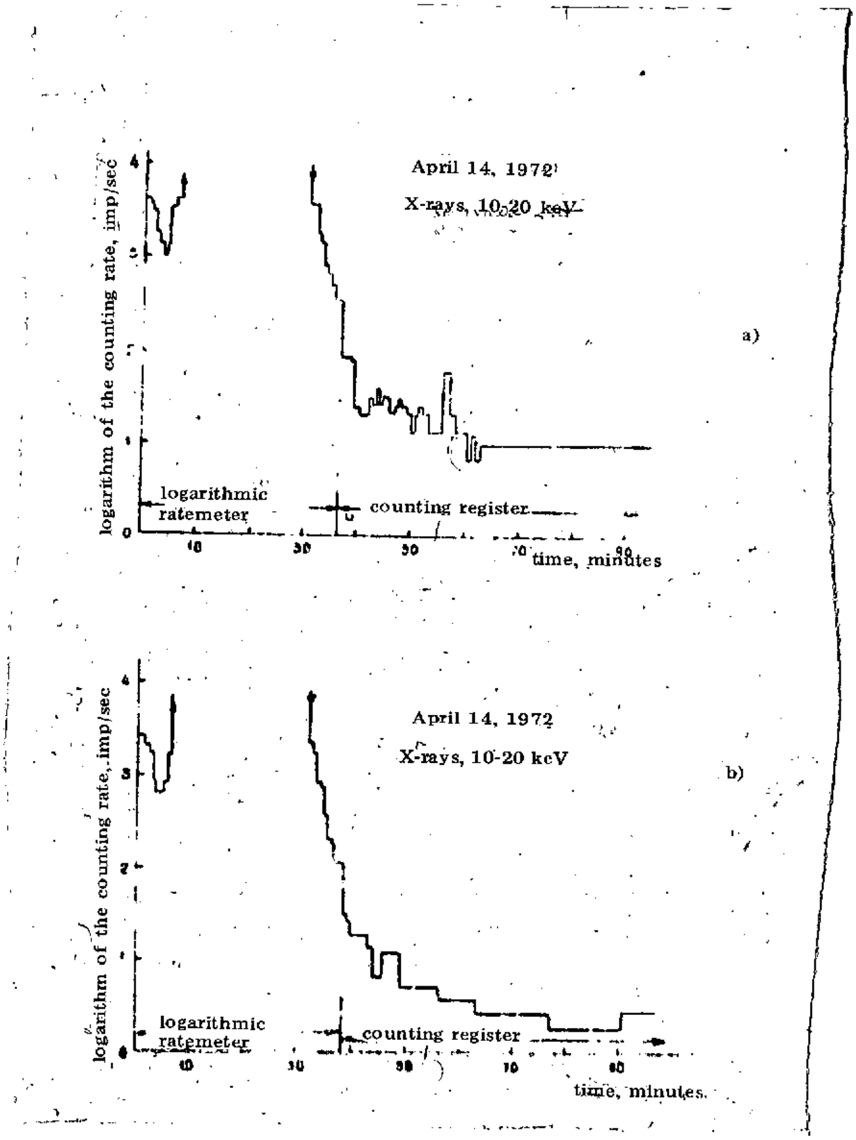

Fig. 37. Recording of the counting rate of the RS-1 instrument: A--channel: 10-20 KeV; B--channel 20-30 KeV. Switching from the logarithmic intensimeter to the summator was accomplished automatically as a function of the drop in intensity.

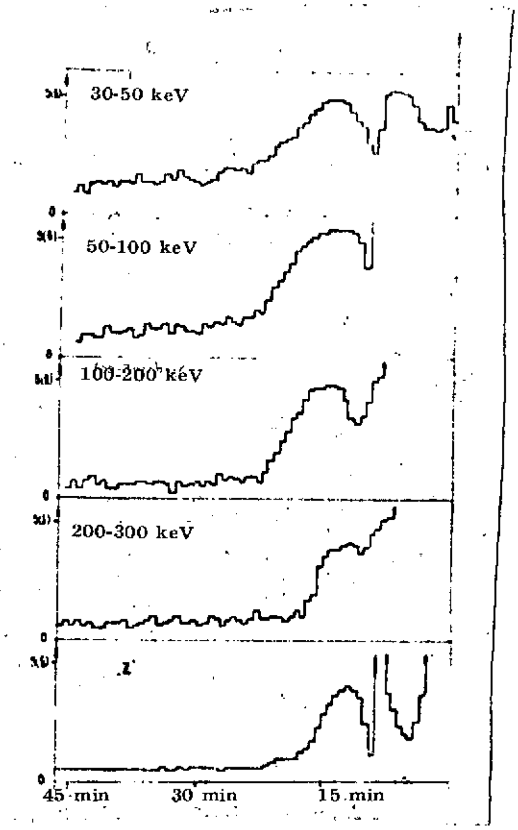

Fig. 38.—Example of a recording of the parameters of the SGL-1 instrument.

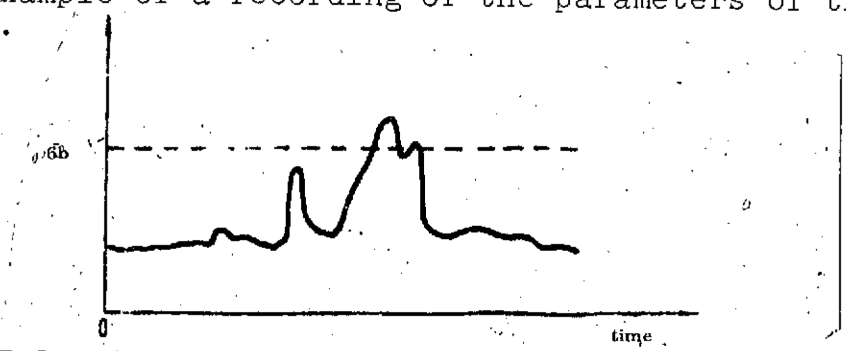

Fig. 39. Telemetric recording of the frequency channel f = 8 kHz of the ANCh instrument.

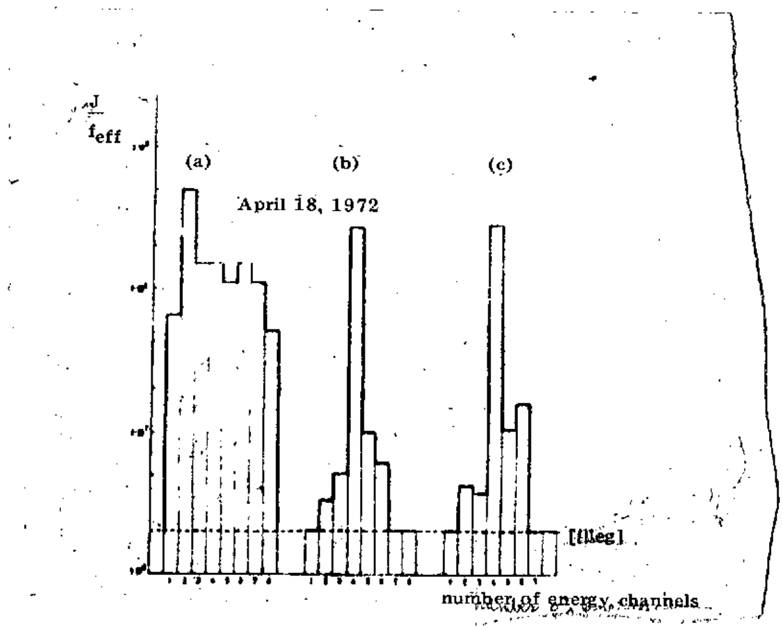

Fig. 40. An example of the recording of the spectra of the plasma of modulation traps PL-18 of the D-140 instrument. The device has eight energy intervals, and E_{av} increases with the number of the channel.

a) Appearance of the spectrum obtained in the transitional layer; b and c) typical spectra of solar wind. J--collector current of trap, e--proton charge; f_{eff} is the effective input area of the trap.

of the D-140 instrument oriented toward the sun, when the satellite is passing through the shock wave, is shown in Figure 41 (ascending branch of the loop). The negative values of current are caused by the recording of electrons with energies above 70 eV and indicate that the satellite is located in a transitional zone between the magnetopause and the shock wave front; positive values are caused by the fluxes of ions and indicate that the satellite has emerged into interplanetary space. One can clearly see the complicated multiple nature of the intersection of the shock wave front. /45

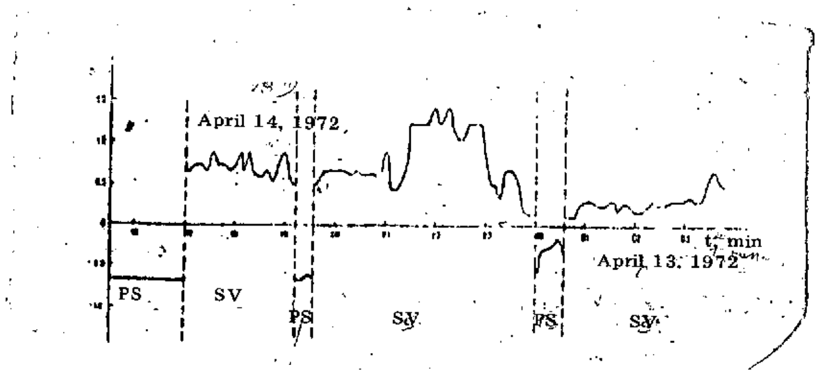

Fig. 41. Example of the recording of the current from PL-46 trap oriented toward the sun. PS--transitional region, SV--solar wind. The level of the current is multiplied by 10^{-9}.

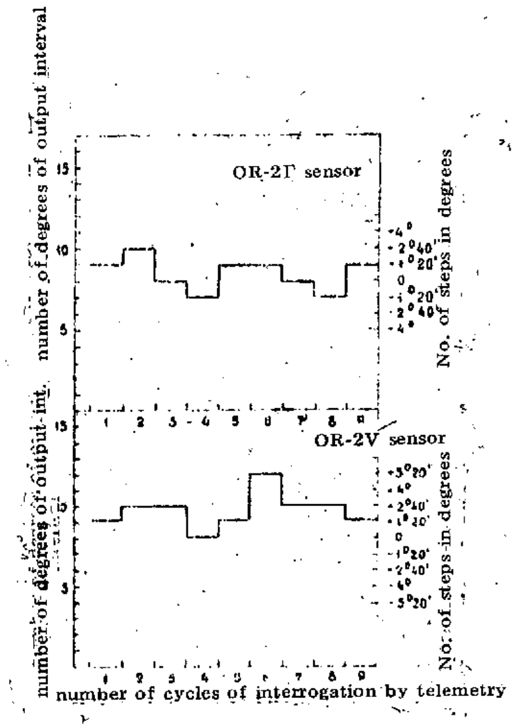

Fig. 42. Recording of the readings of sensors for solar orientation. Sensors OR-2G and OR-2Z are located at angles of 90° to each other.

The dosometric instrument (IK-2P), outside the magnetosphere, records the minimum dose power, when it intersects the region of the magnetosphere the dose of radiation increases sharply.

Judging by the data for the first pass, the magnetic field in the transitional region has a value of 40 gamma, 22 gamma at the shock wave front and 6-8 gamma in interplanetary space.

Figure 42 shows a recording of sensors which measure the position of the X axis of the satellite relative to the direction of the sun.

The information obtained from the "Prognoz" scientific satellites is being analyzed. The results will be published in periodical publications.

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